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# Water Recovery by Membrane Permeation

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RESEARCH into the problems concerned with the recovery of potable water from metabolic waste has progressed to that point wherein several techniques have been studied and evaluated. Reference 1 probably contains the most complete bibliography, description, and evaluation of possible methods for water recovery. Paraphrasing from this report, it is pointed out in the conclusions that the vacuum pyrolysis method in which potable water is produced from mixed human waste and wash water is operationally most advanced. This technique, which has been fully tested both chemically and biologically, was originally devised in this laboratory[2] and further improved under support of NASA.[3] It has certain advantages that other methods do not have. For example, the raw material may be processed immediately after collection with no prior treatment. Also, the recovered product is immediately acceptable in potability and does not require further treatment.

This particular process begins by vaporizing the volatiles in the waste, passing these vapors over a heated catalyst and vapor condensation, resulting in potable water. However, as in other systems, this particular process is hindered by the energy input. Not only is there an energy requirement for the change of state but also a small energy input in the catalytic zone in order that the catalyst be maintained at the proper temperature levels.[4] By proper design,[5] the over-all energy input can be reduced to that point wherein values of power requirements are actually less than the power required to vaporize water. However, problems in engineering design do exist because of the necessity of relatively high temperatures at which the catalyst must be maintained. Thus, the elimination of the catalyst would simplify the technique.

## Permselective Membrane Processes

Kammermeyer[6] of the State University of Iowa discovered the unique high permeation rates of gases through silicone rubber. More recent interest in the use of permselective membrane has been renewed because of the availability of better membranes, having improved strength/thickness ratios and the need for inexpensive separation processes to fulfill the requirements in the fields of medicine and space.

Because different gases go through polymeric films with varying ease, it appeared theoretically possible to separate the water from the other constituents found in urine by vaporizing this water and permitting it to permeate through the membrane. Previous experiments had shown that there was no significant increase in the permeation rate of liquid water when it was placed on one side of the membrane and 500 psig were applied to it. However, the vapor, having a permeation rate orders of magnitude greater than the liquid, would pass through. Consequently, an experiment was derived to check this hypothesis.

### *Experimental*

The experimental setup for this study is simple and consists merely of a still pot having a membrane located over its neck followed by a condenser and a receiver. The raw material, initially a pooled sample of undiluted urine, is placed in the still pot, and the entire system is then evacuated by connection to a vacuum pump. The system pressure is maintained at approximately 40–50 mm Hg (0.77–0.97 psia) where the volatiles in the urine will boil at approximately 40°C (104°F). A collection flow rate of 190 ml/hr (0.2 lb/hr) was maintained with a membrane having a surface area of 85 cm$^2$ (13.1 in.$^2$). The vapor is condensed and collected in the receiver. The collected product was submitted to Betz Laboratories, Philadelphia, Pa., for analysis. The results indicate that the material is potable and contains no odor or color. Figure 1 is an ultraviolet spectrophotometric analysis of distilled water, General Electric catalytic recovered water, Norristown water, and the product derived from the membrane system described previously. As can be seen, the material compares quite favorably with the distilled water reference. Both the "membrane water" and the "catalytic water" are far superior in purity to both the Philadelphia and Norristown water.

Additional experiments were conducted in which the raw material was composed of one part urine to four parts of detergent wash water solution and processed as described earlier. Here again, the recovered product was adjudged potable.

Although all actual experiments conducted with urine were made with one particular membrane composition, many other materials were tested. Polyvinyl alcohol (40.0) and cellulose

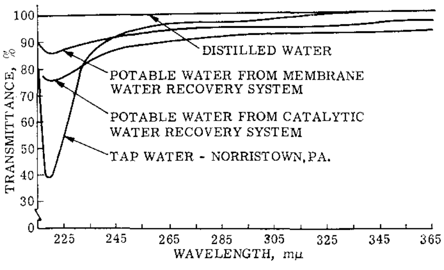

**Fig. 1 Comparison of several water recovery methods by ultraviolet transmittance.**

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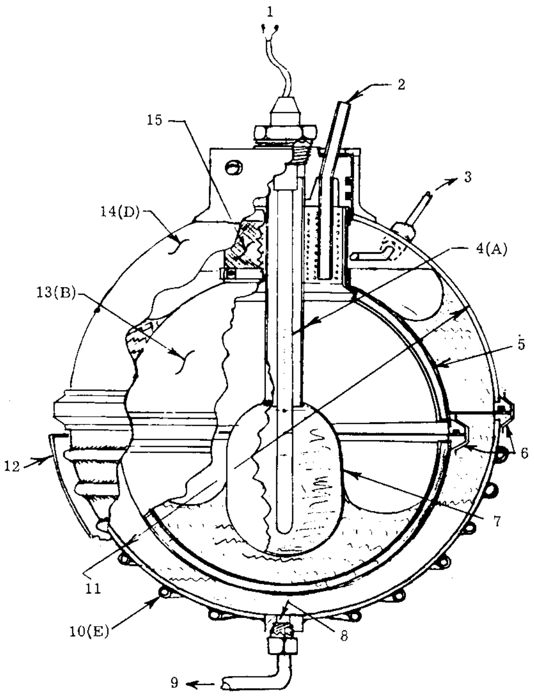


1 ELECTRIC POWER SOURCE (LAB MODEL)
2 FILL PORT
3 TO VACUUM SOURCE
4(A) ELECTRIC CARTRIDGE HEATER (LAB MODEL HEAT SOURCE)
5 DOUBLE WALLED & INSULATED
6 VEE BAND CLAMPS
7 HEATER WELL (FILLED WITH HEAT TRANSFER FLUID)
8 CONDENSATE DRAIN
9 TO RECOVERED WATER STORAGE
10(E) CONDENSING COILS (NOT SHOWN ON UPPER HEMISPHERE FOR CLARITY REASONS)
11 APPROXIMATELY 17" DIAMETER
12 OUTER INSULATING JACKET (TYPICAL ALL AROUND BOTH HALVES)
13(B) URINE STORAGE & VAPORIZATION CHAMBER
14(D) CONDENSATION & COLLECTION CHAMBER
15 PERMSELECTIVE MEMBRANE SURFACE

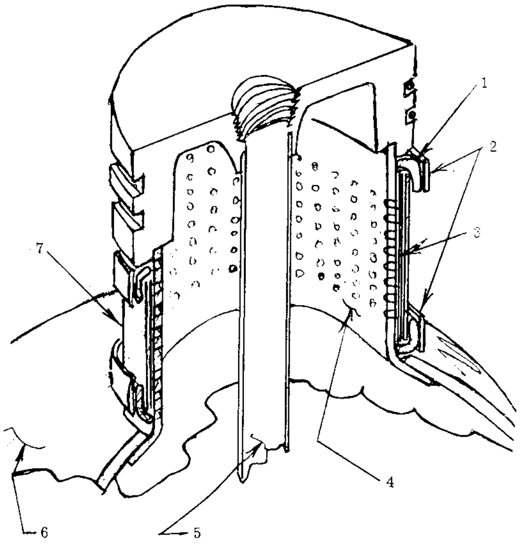
**Fig. 2 Potable water recovery unit.**

acetate (19.4) came close to having water vapor permeation rates equal to that of silicone rubber (15.5 to 51.8 g-cm/sec-cm$^2$-cm Hg). However, the silicone rubber materials offer further advantages in that they have a high temperature strength and stability greater than the other materials and they are more difficult to hydrolyze which indicates that they have an inherently longer life.

### *Equipment design*

The recovery system (Fig. 2) is designed as a single integral package in the form of a sphere and has a capacity of 20 lb/day water output. Referring to Fig. 2, the heat source, a cartridge heater, is contained within a spheroidal heater well that is located off-center within the spherical vaporization chamber. The heater well has sufficient surface area to efficiently accomplish the required boiloff rate and is filled with a fluid that has high thermal conductivity to enable the efficient transfer of heat between the cartridge heater and the urine supply.

The well is fabricated from stainless steel as is the vaporization chamber. This material gives a wettable surface, which along with the geometry of the surfaces and their relative locations assures the proper positioning of the vapor bubble within the chamber as well as the physical positioning of the vapor well and the liquid urine for all supply levels. By fabricating the vaporization chamber as two easily separable double-walled hemispheres, the periodic clean-out of semisolid residues is accomplished with a minimum of effort. The insulated double wall minimizes heat losses from the vaporization chamber.



1 MEMBRANE EDGE SEALING GASKET
2 EDGE SEAL CLAMP RINGS
3 PERMSELECTIVE MEMBRANE (SANDWICHED BETWEEN SUPPORT STRUCTURES)
4 PERFORATED STAINLESS STEEL INNER SUPPORT STRUCTURE
5 HEATER WELL (REF.)
6 VAPORIZATION CHAMBER (REF.)
7 FINE MESH STAINLESS STEEL SCREEN OUTER SUPPORT STRUCTURE

**Fig. 3 Detail section through permselective membrane assembly.**

The permselective membrane assembly is located around the perimeter of a "neck" at the top of the vaporization chamber where the vapor bubble can be expected to form under both gravity field and weightlessness conditions. By referring to Fig. 3, the details of the membrane installation can be seen. The membrane is structurally supported by backup surfaces on both sides, the perforated vaporization chamber neck on the upstream side, and a fine mesh stainless-steel screen on the downstream side. Edge leakage around the membrane is prevented by gasket rings. The membrane performs the additional function of acting as a phase separator to prevent urine splash-over or water backwash within the system under all conditions of operation.

The outer condensing chamber is also formed from easily separable hemispheres of stainless steel which are clamped together with a "vee" band coupling and sealed by an "O" ring. The condensing fluid coils are welded to the exterior of the condenser hemispheres and jacketed with suitable thermal insulation to minimize heat gains from cabin or laboratory atmosphere.

### *Power requirements optimization*

The power requirement for a flight optimized water recovery system can be minimized by integration with the over-all vehicle thermal control system. The main energy requirement input is the heat of vaporization. This requirement amounts to some 300 w, for a 20 lb/day capacity, assuming that the system operates continuously. The waste heat resulting from cooling the electronic equipment aboard a fully operational manned space vehicle would be of sufficient magnitude and at a proper temperature level (approximately 130°F) to supply the 300-w input to the system. By utilizing this waste heat, the vaporization chamber power penalty amounts to only that required to circulate the heat-transfer fluid between the electronic cooling loop and the vaporization chamber.

The remaining significant power requirement for an optimized system would be that required to operate a pump that circulates coolant between the condensation chamber and the

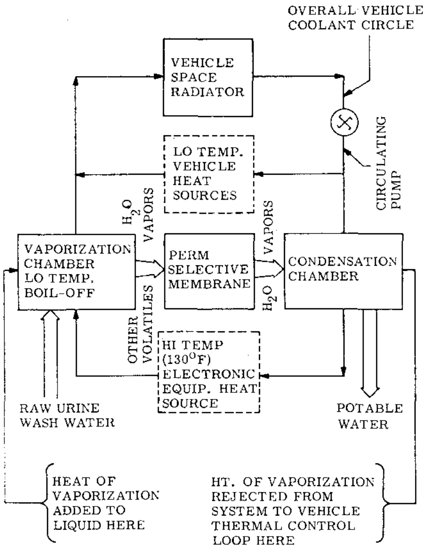


**Fig. 4 Flow process: vehicle integrated membrane water recovery system.**

vehicle heat injection means, most likely a space radiator. Figure 4 illustrates schematically the integration of a flight optimized system. It is estimated that the power penalty which should be assessed against such a system would total 10–20 w continuous plus control power. The pumps shown would already be required as a part of the vehicle thermal control system, and they would merely have to be increased in capacity to handle the additional pumping load.

As an alternate means, the incorporation of a compressor within the water recovery system was considered which would render the system independent of integrated heat sources or sinks from other systems within the vehicle. An electrical power requirement would exist for the compressor motor, relays, indicator lamps, etc. With this system, final condensation heat would be used directly to supply heat of vaporization to the still pot for initial boiloff. The pressure of the boiled-off vapor out of the vaporization pressure chamber of the system would be increased by the compressor to a sufficiently high level to insure a $\Delta t$ of at least 10°F in the boiling-condensate heat-exchange relationship. This requires a compressor $\Delta P$ of at least 0.35 psi or a compression ratio of 1:1.5 minimum. At a temperature of 110°F, the vapor must be moved at the rate 350 ft$^3$/lb of water processed, or 290 ft$^3$/hr. A suitable compressor to perform this pumping rate would have a speed of approximately 1200 rpm, which results in a "piston displacement" of 6.6 in.$^3$ At a compressor efficiency of 0.8, a net "displacement" of at least 8.25 in.$^3$ would be required.

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# Volatile Liquid Pressurization Control System

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THE small bipropellant rocket engines being used for the control of aerospace vehicles require a storage and pressurization system that is light, compact, and compatible with high-energy propellants. A common technique employs high-pressure nitrogen or helium, which is separated from the propellants by Teflon or metallic bladders, but storage of these gases may require tank volumes and weights greater than those for the propellants, and gas-flow control devices are required. Several alternate approaches show potential weight and volume savings. For example, the use of a chemical reaction inside the main propellant tanks[1] may be quite advantageous for booster applications where high flow rates are required over a relatively short operational time. The system presented in this note is intended for use primarily in space vehicles having extended periods of on-off operation or for tactical missiles having lower flow rates but more stringent packaging requirements. It uses a volatile liquid, which is stored within the propellant tank and encloses an electrical heating element that maintains the required supply pressure by vaporizing the liquid (Fig. 1). The heat addition can be regulated by the supply pressure itself, the thrust command, or a combination of these. A comparison of pressurization system weight, which includes pressurant, pressurant tank, and propellant tanks, is presented in Fig. 2. The weight of the battery required for the volatile liquid system is excluded, as is the weight for lines, fittings, valves, and pressure regulators necessary to the nitrogen and helium systems. Even a fluorinated hydrocarbon of high molecular weight provides a weight saving over the $N_2$ system for chamber pressures up to 150 psia. The use of ammonia significantly reduces the weight; such potential weight and volume reductions warrant further investigation of this concept.

### Governing Equations

The Laplace transfer function describing the ratio of propellant flow rate $\dot{w}_p(s)$ to the command signal $C(s)$ supplied by the guidance system is given by

$$\dot{w}_p(s)/C(s) = K_1/(s + K_2) \qquad (1)$$

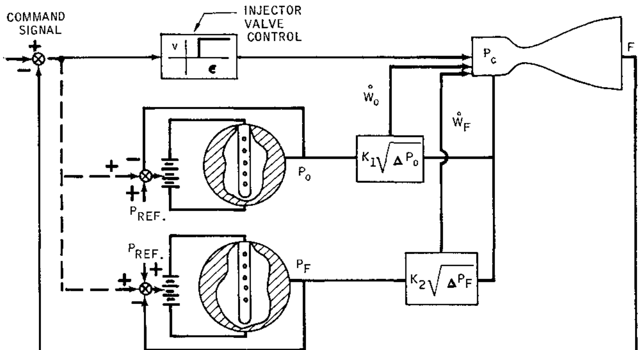

**Fig. 1 System block schematic.**

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