Multi-Filter System for Water Reclamation

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ABSTRACT

A study was made of the expected composition of dehumidification water and wash water in a space station. Multi-filter subsystems containing activated carbon, ion exchange resin and a particulate filter were designed and tested. The dehumidification water subsystem produced potable water from air-conditioning condensate obtained from a space simulator. The wash water subsystem treated used wash water and produced water suitable for reuse as wash water. Chemical, bacterial, and organoleptic results are given.

The multi-filter system uses no electric power, has no moving parts, is highly reliable, and is ideally suited for operation under weightless conditions. It is not suitable for use with urine because of the relatively high solute concentration of urine.

TWO WASTE WATER SOURCES in a space station are dehumidification water and wash water. For a three-man crew about 7.5 lb/day of humidity condensate and 12 lb/day of wash water will be produced. Both of these waste waters have relatively low solute concentration and can readily be reclaimed by treatment with activated carbon and ion exchange resin. The advantages of this approach are obvious:

1. The process is very simple in operation and control.
2. The system operates at essentially ambient pressure so that no leak problems are anticipated. Operating temperature is also ambient.
3. The filtration process has inherent "zero-g" capability.
4. No power is required and no moving parts are used (assuming the use of a differential pressure between the feed and product storage tanks).
5. Very little corrective maintenance is anticipated for a system of this type.

Disadvantages of this approach are:

1. The waste water does not undergo a change of phase, thus the chances of unexpected, non-volatile impurities passing through the system may be greater for this technique than for a distillation process.
2. It is not suitable for use with raw urine because of the excessive weight of carbon and resin required.
3. Expendable weight is variable, therefore the weight of the system would increase for longer missions (unless the activated carbon and ion exchange resin could be regenerated aboard the spacecraft).

The objectives of this program were to develop two subsystems: one to recover potable water from humidity condensate, the other to reclaim used wash water for re-use as wash water.

DEHUMIDIFICATION WATER COMPOSITION

The water to be treated in this subsystem will be produced by the cabin air dehumidifiers. Broadly speaking, this condensate is expected to be relatively pure water. The exact nature and quantity of contaminants are difficult to predict since they would depend on a number of factors, such as:

1. Type of system used for oxygen supply and CO_2 removal.
2. Auxiliary equipment used for removal of trace contaminants in the cabin atmosphere; e.g., a catalytic burner for oxidizing contaminants and/or activated carbon for adsorbing contaminants.
3. Materials of construction used for the condensate coils.
4. Nature of paints, coatings, insulation, etc. used in the cabin and cabin equipment.
5. Nature of lubricants, greases, or other substances used to operate cabin equipment.
6. Degree of contamination of cabin air from other subsystems; e.g., feces collection or storage subsystem.

In spite of the above uncertainties, some useful data is available from current submarine and space cabin simulator systems. This information is summarized in the following paragraphs.

Submarine Condensate

Samples of air conditioning condensate from nuclear submarines collected during periods of sealed operation have occasionally been obtained. Typical results are shown in Tables I through IV. These samples were collected from the forward torpedo room air conditioning drain. This compartment has a relatively heavy "crew load." As expected, the total concentration of contaminants in all these samples is low; i.e., less than 90 ppm. This water would be potable, except for the following possible objections:

1. Copper contamination introduced by the materials of construction in the condensate systems.
2. Odor, slight in some samples; strong, unpleasant stale tobacco odor in others.
3. The apparent variability in bacterial contamination.

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TABLE I. AIR CONDITIONING CONDENSATE; SS(N)571

Total suspended solids(1)	22 ppm
Total dissolved solids(2)	43 ppm
pH	7.1
Bacterial count (standard plate count method; 40 hour incubation at 35° C)(3)	1 x 10⁵ organisms/ml

Semi-quantitative Spectrographic Analysis of Dried Residues from Above Sample (Used to calculate values in Table II)

	Suspended Solids	*Dissolved Solids(2) (alcohol insoluble)*
> 10%	None	Ca, Cu
1-10%	Al, Cr, Cu, Fe, Si, Ti, Zn	Si, Zn
0.1-1%	Ca, Mg, Ni	Al, Ba, Cr, Fe, Mg, Ni, P, Na
0.01-0.1%	Pb, Mn, Zr	B, Mn, Sn, Ti

NOTES
(1) Collected on 0.45 micron filter. Microscopic examination indicated suspended solids to be mainly corrosion products and dirt.
(2) The dissolved solids residue appeared to be oily; 63% was soluble in methyl alcohol. Identification of alcohol soluble fraction was attempted but was unsuccessful. Analysis of alcohol insoluble fraction is shown above.
(3) "Standard Methods for the Examination of Water and Waste Water," American Public Health Association,[3] 11th Edition, p. 492.

TABLE II. ANALYSIS OF AIR CONDITIONING CONDENSATE; CALCULATED FROM SEMI-QUANTITATIVE SPECTROGRAPHIC ANALYSES OF RESIDUES (SEE TABLE I)

Elements Found	*Concentration (Calc.) in Water Sample*
Cu, Ca	2 ppm
Si, Zn	0.4 - 4 ppm
Al, Cr, Fe, Ti	0.2 - 2 ppm
Mg, Ni	0.04 - 0.4 ppm
Ba, P, Na	0.02 - 0.2 ppm
Mn	0.004-0.04 ppm
Pb, Zr, B, Sn	0.002-0.02 ppm

TABLE III. AIR CONDITIONING CONDENSATE; SS(N)585

Total solids, ppm.	39
Copper, ppm	1.0
Chloride, ppm	2.5
pH	7.2
Conductivity, micromhos/cm	430
Color, units (platinum—cobalt scale)	50
Odor intensity (cold)	III
Bacterial examination:	
Routine bacteria count	No growth in 96 hours at any dilution
Desoxycholate plates	No growth in 96 hours
Eosin methylene blue plates	No growth in 96 hours
Blood agar plates	No growth in 96 hours
Thioglycolate tubes blue plates	No growth in 96 hours

TABLE IV. AIR CONDITIONING CONDENSATE; SSB(N)602

Conductivity	450 micromhos/cm
pH	7.7
NH_4^+	positive
Cl^-	negative
SO_4^{--}	negative
C.O.D.	477 ppm
Total solids	85 ppm
Organoleptic tests:	
Appearance	slightly turbid, much sediment
Odor	strong, unpleasant stale tobacco smoke
Color	light amber

Evidence indicates that water recovered from a submarine air conditioning system is potable. For example, during a trip of the U.S.S. TRIGGER in 1952, the seawater distilling unit broke down and the crew drank water collected from the air conditioning system without ill effect. Some of the crew found the taste slightly objectionable and preferred to flavor their water with chocolate syrup.

Space Cabin Simulator Condensate

There is little published information on the composition of air conditioning condensate in a space simulator, mainly because such few systems have been operated under sealed conditions for extended periods. However, information on trace *atmosphere* contaminants has been obtained.[2,3,6] Using such data, it is possible to estimate the concentration of these contaminants in the dehumidification water in equilibrium with the atmospheric contaminants.

Consider methyl alcohol as an example. This contaminant was selected for a sample calculation because: 1) it can be of metabolic origin, 2) it is toxic if ingested, 3) it is infinitely soluble in water, and 4) vapor-liquid equilibria data for the water-methanol system are available. A sample calculation was made based on the assumptions that: 1) the concentration of methanol in the atmosphere is 0.85 microgram/liter (maximum detected in space cabin simulator)[2]; 2) equilibrium will be reached between the methanol concentration in the atmosphere and the methanol concentration in the water.

This latter assumption is conservative, since with condensate continuously being formed and removed, it is doubtful that equilibrium will be reached. The maximum concentration of methanol in the condensate is calculated to be only 0.1 ppm.

Under conditions of "average" concentration of methanol in the atmosphere and a more realistic assumption of 50 per cent of equilibrium concentration, the condensate will contain less than 0.05 ppm methanol.

For atmosphere contaminants that have low solubility in water, the concentration in the condensate, relatively speaking, will be even lower. This is because the equilibrium curve (the so-called x-y diagram) will be very steep at low concentration of contaminant. In the case of benzene, for example, the condensate (in equilibrium with 0.2 microgram/liter in the atmosphere) would contain a maximum concentration of roughly 0.01 ppm benzene.

An analysis of a sample of condensate from the Wright-Patterson Air Force Simulator, used in our test program, is given in Table VI. Compared to submarine condensate, this water is of slightly better quality and does not have the stale tobacco odor.

Based on the above data and discussion, it is concluded that the dehumidification water from a space simulator will contain the following maximum impurity levels:

Total solids —70 ppm
Total particulate matter—25 ppm
Total dissolved solids —45 ppm (approx. ½ organic and ½ inorganic)

This water should be potable except for the possible presence of pathogenic micro-organisms and a slight odor.

WASH WATER COMPOSITION

There will be 4 lb (neglecting evaporation losses) of used wash water per man-day containing:

1. Additives, such as benzalkonium chloride (BAC), the cleanser of choice.[4]
2. Secretions of skin, i.e., sweat and sebum.
3. Dirt and skin dust (hair, dead skin, etc.).

Again, several variables make it difficult to reach definitive conclusions as to the quantitative composition of dirty wash water.

1. Amount of residue on skin would vary depending on temperature, humidity, and amount of dirt in environment.
2. Variations due to activity of subject.
3. Variations due to absorption by clothing.
4. Variations due to intervals between "baths" and method of bathing, e.g., amount of rubbing.
5. Individual variations between subjects.
6. Variations due to diet and amount of water consumed.

It can be assumed, however, that ingredients generally present in sweat will be present in wash water in lesser concentrations.

A literature survey[4] was made to determine what concentrations of impurities should be expected in used wash water. In addition, analyses were made on wash water collected from bathing. Washing was carried out using a basin and wash-cloth. One subject bathed about three times weekly for approximately one month using 4-lb of water containing 0.1 per cent BAC for each bath, and the method proved psychologically satisfactory. A composite sample was prepared by blending fifteen 4 lb samples of "dirty" wash water. Based on analyses made on this composite sample, along with information uncovered in the literature, the composition of major constituents in typical wash water was estimated to be that summarized in Table V. Total

TABLE V. ESTIMATED COMPOSITION OF WASH WATER (MAJOR CONSTITUENTS)

Soluble solids (does not include BAC)	550 ppm
Insoluble solids	1000 ppm
Urea	100 ppm
Chloride	240 ppm
BAC (cleansing agent)	500 ppm
Lactic acid	76 ppm
Lipids	180 ppm

solids, including BAC, are approximately 0.25 per cent. The concentration of BAC is shown as 0.05 per cent since later tests showed this to be more than adequate.

MULTI-FILTER TEST RESULTS

Based on the results of a laboratory test program,[4] two multi-filter subsystems were designed and built.[5] The dehumidification water system, shown in Figure 1, consists of a canister containing activated carbon and a 0.45 micron bacterial filter. Ion exchange resin was not considered necessary because of the anticipated low level of ionic contaminants.

The wash water system, shown in Figure 2, consists

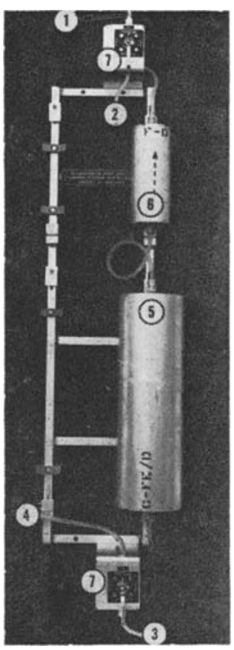

Fig. 1. Dehumidification Water Subsystem

(1) To reclaimed water tank
(2) Sample line
(3) Compressed air supply
(4) From waste water storage tank
(5) Carbon canister
(6) Bacterial filter
(7) Two-way valves

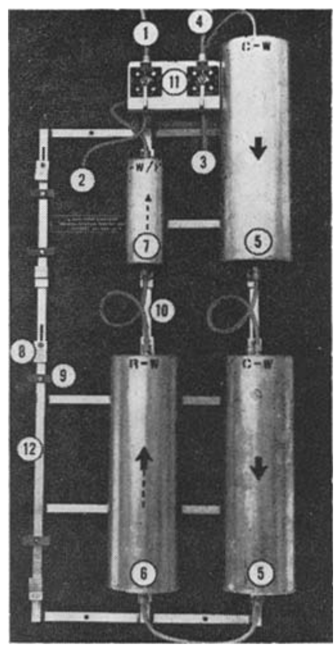

Fig. 2. Wash Water Subsystem

(1) To reclaimed water storage tank
(2) Sample line
(3) Compressed air supply
(4) From waste water storage tank
(5) Carbon canisters
(6) Resin canister
(7) Particulate filter
(8) Beveled canister retainer
(9) Phenolic plastic canister saddle
(10) Aluminum channel frame
(11) Two-way valves
(12) Replacement support position

of two carbon canisters, one resin canister, and a particulate filter. The problem of bacteria removal was approached by the use of a germicidal cleansing agent (BAC) in the fresh wash water.

The weights of these subsystems, as a function of mission length, is given in Figure 3. These weights,

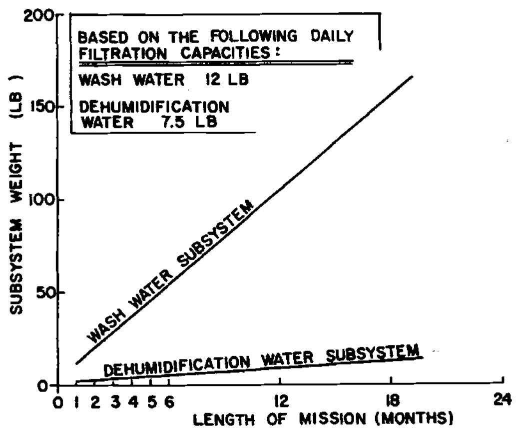

Fig. 3. Weight versus mission length for multi-filter subsystems.

of course, are based on the anticipated waste water compositions given earlier. For a three-month mission (or a mission with resupply at three-month intervals), the dehumidification water reclamation unit weighs about 5 lb and the wash water reclamation unit weighs about 30 lb.

Both of the multi-filter systems were tested on waste waters. Because of the limited quantities of waste water available, extended testing could not be undertaken. However, the test results obtained do show that the treated water from each subsystem meets the required specifications. Frequency of canister replacement was not determined experimentally, but was calculated from theoretical considerations and from prior laboratory results.[4] Canister and filter life for the wash water subsystem is expected to be one month. Life expectancy for canisters in the dehumidification subsystem is three to six months. Since replacement frequency is highly dependent on composition of the waste waters, canister life can best be determined in extended tests with manned space simulators.

For evaluating the wash water subsystem, a concentration of 0.05 per cent BAC was used as the washing agent. About 12 lb of used wash water from three volunteers were treated in the wash water subsystem and the clean effluent collected. Four pounds of this effluent were used for all subsequent testing. This clean effluent was soiled by daily bathing, purified in the subsystem, and reused through five complete cycles. Small quantities of water were removed for samples and this loss was corrected by adding waste wash water before recycling. The flow rate of the wash water was maintained at approximately 10 ml/min (1.3 lb/hr) resulting in a pressure drop in the multi-filter of 0.5 to 2 psig.

The results of tests with the wash water recovery subsystem are shown in Table VI. The results indicate that not only did the unit yield water suitable for use as clean wash water, but also the effluent water after five cycles apparently met the U. S. Public Health Service drinking water standards.[1]

A recovery efficiency of 99.0 per cent was calculated for the wash water system. This efficiency was calculated on the basis of the amount of water remaining in the activated carbon, ion exchange resin, and filters after these canisters were drained of excess water by blowing with air. Losses due to evaporation were not taken into consideration since this water would be recovered by the dehumidification system in a space cabin.

Dehumidification water for testing the system was obtained from the space cabin simulator at Wright-Patterson Air Force Base. The simulator water had an "organic" odor which was not unpleasant. The waste water was passed through the subsystem at a flow rate of 10 ml/min. giving a pressure drop of from 0.5 to 0.9 psig. The results of tests with recovered water from the space simulator are shown in Table VI. The recovered simulator water apparently meets the United States Public Health standards for drinking water. A recovery efficiency of 99.5 per cent was calculated for the dehumidification system.

TABLE VI. SUMMARY OF TYPICAL ANALYSES

	WASH WATER		*SIMULATOR DEHUMIDIFICATION WATER*	
	WASTE	*PROCESSED*	*WASTE*(4)	*PROCESSED*
Conductivity, micromhos/cm	525	Below 20	150	66
pH	4.8	7.2	7.1	7.2
NH_4^+	sl. pos.	sl. pos.(3)	pos.	neg.
Cl^-	pos.	neg.	neg.	neg.
$SO_4^{=}$	neg.	neg.	neg.	neg.
BAC,(1) ppm	400+	neg.	....	....
Urea	pos.	neg.	....	....
Appearance	Turbid and sediment	clear	sl. turbid some sediment	clear
Odor	typical	none	sl., not unpleasant	none
Color	grayish	none	none	none
Taste	....	none	....	satisfactory
COD,(2) ppm	1200	50	450	85
Total solids, ppm	2350	26	60	70
Bacteria: total count	....	....	too numerous to count	none
coliform	....	....	3/100 ml	0/100 ml

(1) Benzalkonium chloride added as cleansing agent.
(2) Chemical Oxygen Demand is related to organic material in sample.
(3) This questionable slight positive test was traced to the ion exchange resin.
(4) Condensate from AMRL Simulator.

SUMMARY

The multi-filter subsystems were tested and found to give recovered water of the required quality. The dehumidification water subsystem produced potable water from air conditioning condensate obtained from a space simulator. The wash water subsystem produced water suitable for re-use as wash water.

The multi-filter scheme is recommended on the basis of its high reliability, simplicity, zero power requirement, and inherent "zero-g" capability.

The frequency of canister replacement, and hence subsystem weights, are highly dependent on the composition of the waste waters. Canister life can best be determined by test operation in a manned space simulator.

Based on the amount of water remaining in the subsystems, the following water recovery efficiencies were calculated:

Dehumidification water subsystem	99.5%
Wash water subsystem	99.0%

Four pounds of wash water were found to be sufficient for bathing purposes and it is felt that even a lesser amount might be sufficient.

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