NASA CR-66640

SIXTY DAY MANNED EVALUATION OF ZERO GRAVITY HUMIDITY CONTROL SYSTEM

Prepared under Contract No. NAS 1-5622

by

Biotechnology Organization
Lockheed Missiles & Space Company
Sunnyvale, California

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LANGLEY RESEARCH CENTER, LANGLEY STATION, HAMPTON, VIRGINIA

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LIST OF CONTRIBUTORS

Name	Area of Contribution
R. W. Joy	Project Leader
R. C. Tuttle	Chemical Analysis
T. E. Adamson	Report Integration
T. M. Olcott	Technical Advisor

NASA Technical Monitor

C. Saunders

Life Support Section
Flight Instrumentation Division
NASA Langley Research Center

CONTENTS

ILLUSTRATIONS

SIXTY DAY MANNED EVALUATION OF ZERO GRAVITY HUMIDITY CONTROL SYSTEM

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INTRODUCTION AND SUMMARY

The LMSC Biotechnology Organization began in 1963 to study the application of hydrophilic and hydrophobic surfaces for phase separation in low gravity environments. A humidity control system using these surfaces was fabricated by LMSC in 1966 and delivered to NASA/LRC under Contract NAS 1-5622. As a part of a follow on to the contract, LMSC was requested to conduct an evaluation and testing phase. This evaluation program is described in CR-66543*. The previous evaluation program consisted of four parts: development of evaluation criteria and test plan, system integration and checkout, initial steady state tests and test plan modifications, final steady state and performance evaluation testing and test data analysis, and development of optimum design criteria. Upon the successful completion of the evaluation testing of the zero gravity humidity control system, NASA Langley Research Center directed Lockheed Missiles & Space Company to provide a humidity control system for the McDonnell Douglas spacecabin simulator to be used during a 60-day manned test in that simulator. The unit was incorporated into the potable water recovery system for urine and atmospheric condensate. This unit included an aluminum plate-fin condensing heat exchanger, a hydrophobic/hydrophilic water separator and a continuous water delivery system.

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*Evaluation Testing of Zero Gravity Humidity Control System by Thomas M. Olcott and Richard A. Lamparter, NASA CR-66543, 25 October 1957

DESCRIPTION OF ZERO GRAVITY HUMIDITY CONTROL SYSTEM

The zero gravity humidity control system is designed to condense and remove water from an enclosed environment in order to prevent high humidity build up and to provide water for reuse. A photograph of the humidity control system is shown in Figure 1. Figure 2 is a schematic of the system. The water delivery system electrical schematic is presented in Figure 3. The system is designed to separate liquid from gas using the hydrophobic/hydrophilic surface technique. Moist gas is passed through a condensing heat exchanger where the moisture is condensed. The cooled gas with the entrained water is then delivered to the water separator where the water is removed from the cabin atmosphere by a hydrophobic cone and directed to one of three hydrophilic sumps. The hydrophilic sumps allow the water to pass freely, but not the cabin atmosphere. A pump, controlled by a differential pressure switch which senses the ΔP across the sump, is used to deliver the water to a storage tank. The water pump maintains a preset suction pressure across the sump. The tube leading away from the sump remains full of liquid to maintain the water-screen surface tension bond which prevents gas from passing through the hydrophilic sump. A solenoid valve also operated by the ΔP switch is installed in series with the pump.

The saturated cabin atmosphere passes through the hydrophobic cone and is returned to the cabin. The hydrophobic surface allows the cooled saturated gas to pass but separates the water droplets. The water droplets are carried by the gas stream to the hydrophobic cone but do not pass through it since their diameter is larger than the openings in the screen and the impact pressure is less than the pressure required to maintain a stable liquid gas interface in the screen openings.

A detailed operating procedure for this system is presented in Appendix A.

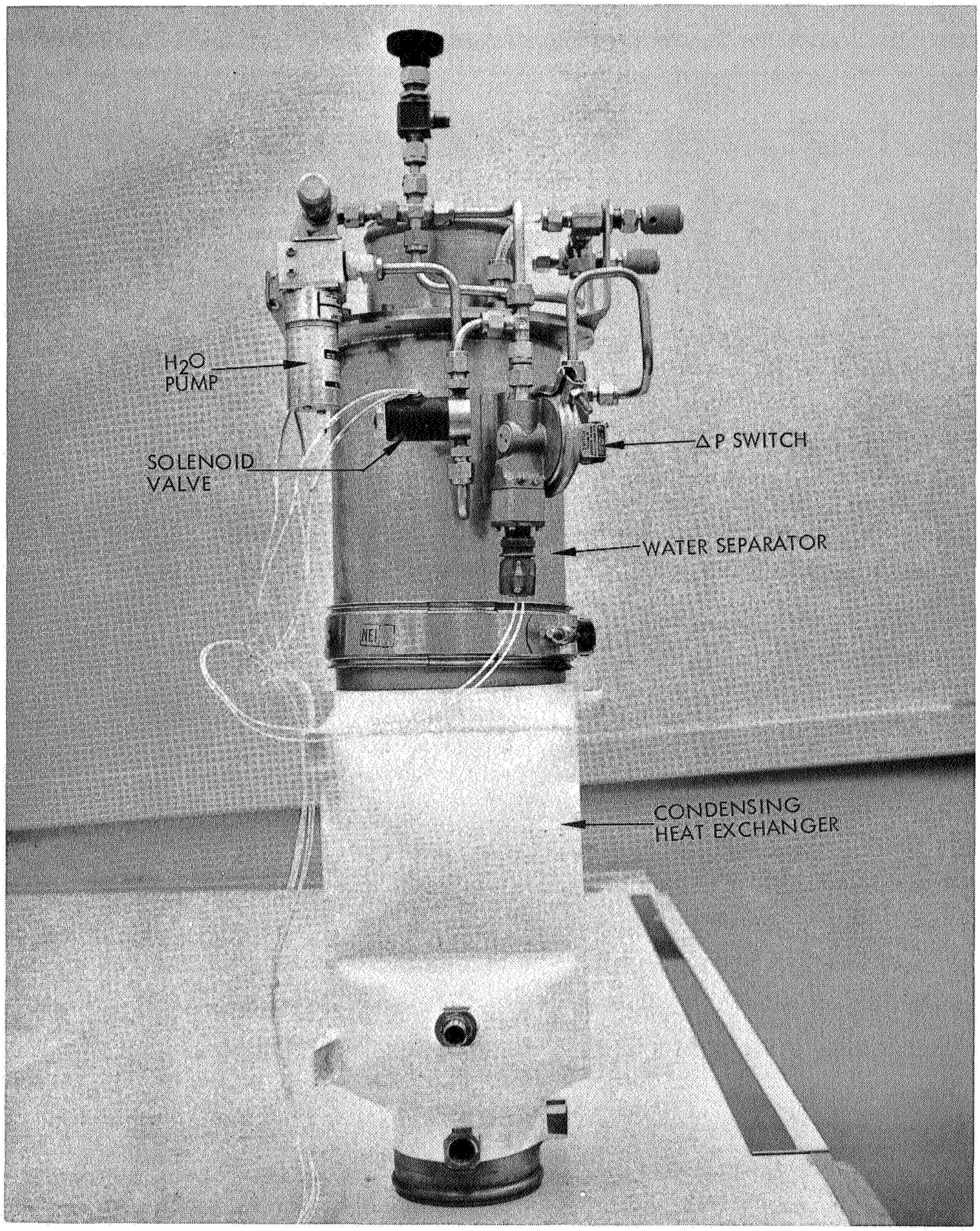

Fig. 1 - LMSC Zero Gravity Humidity Control System

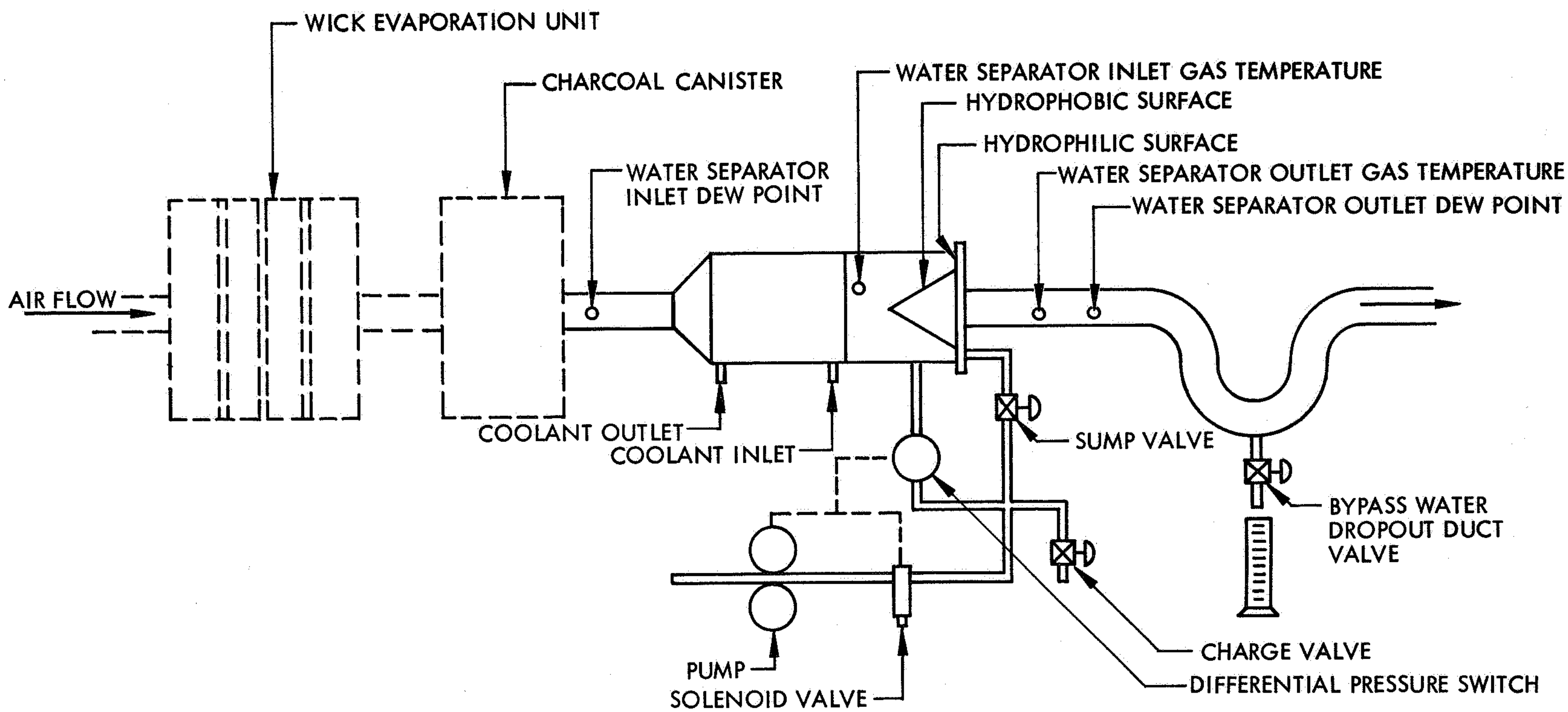

Fig. 2 - LMSC Zero Gravity Humidity Control System Schematic

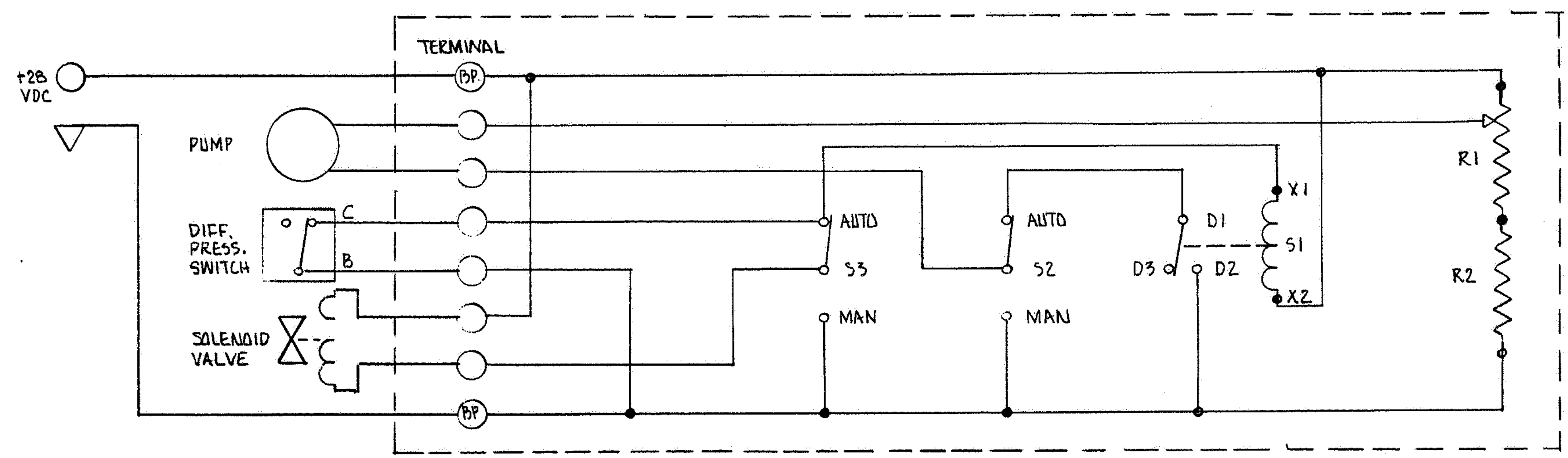

Fig. 3 - Electrical Schematic of the Water Separator Control Circuit

DESCRIPTION OF McDONNELL DOUGLAS POTABLE WATER RECLAMATION SYSTEM

In the McDonnell Douglas 60-Day test, the Lockheed humidity control system was integrated with the water reclamation system as shown in Figure 4. In this loop, cabin atmosphere passes over heated wicks which are saturated with urine. Water from the urine brine evaporates into the gas stream raising the relative humidity, leaving a more saturated brine behind in the wicks. During the evaporation process some contaminant gases also enter the cabin gas stream. The humidified gas leaving the evaporator then passes through an activated charcoal bed where many of the contaminant gases are removed. The resultant gas stream containing the water from the cabin and the urine evaporator then enters the condensing heat exchanger of the Lockheed humidity control system. In the condenser the bulk of the inlet water is condensed as the gas temperature is dropped to approximately 45°F. Free water and gas with a low absolute humidity from the heat exchanger then pass through the Lockheed water separator. The gas passes through a hydrophobic cone, which separates out the free water, and passes back to the cabin. The free water is deflected by the hydrophobic cone to hydrophilic sumps where it is removed from the humidity control system. Water is pumped from the sumps through a silver ion generator to the potable water sterilization unit and kept in heated storage tanks.

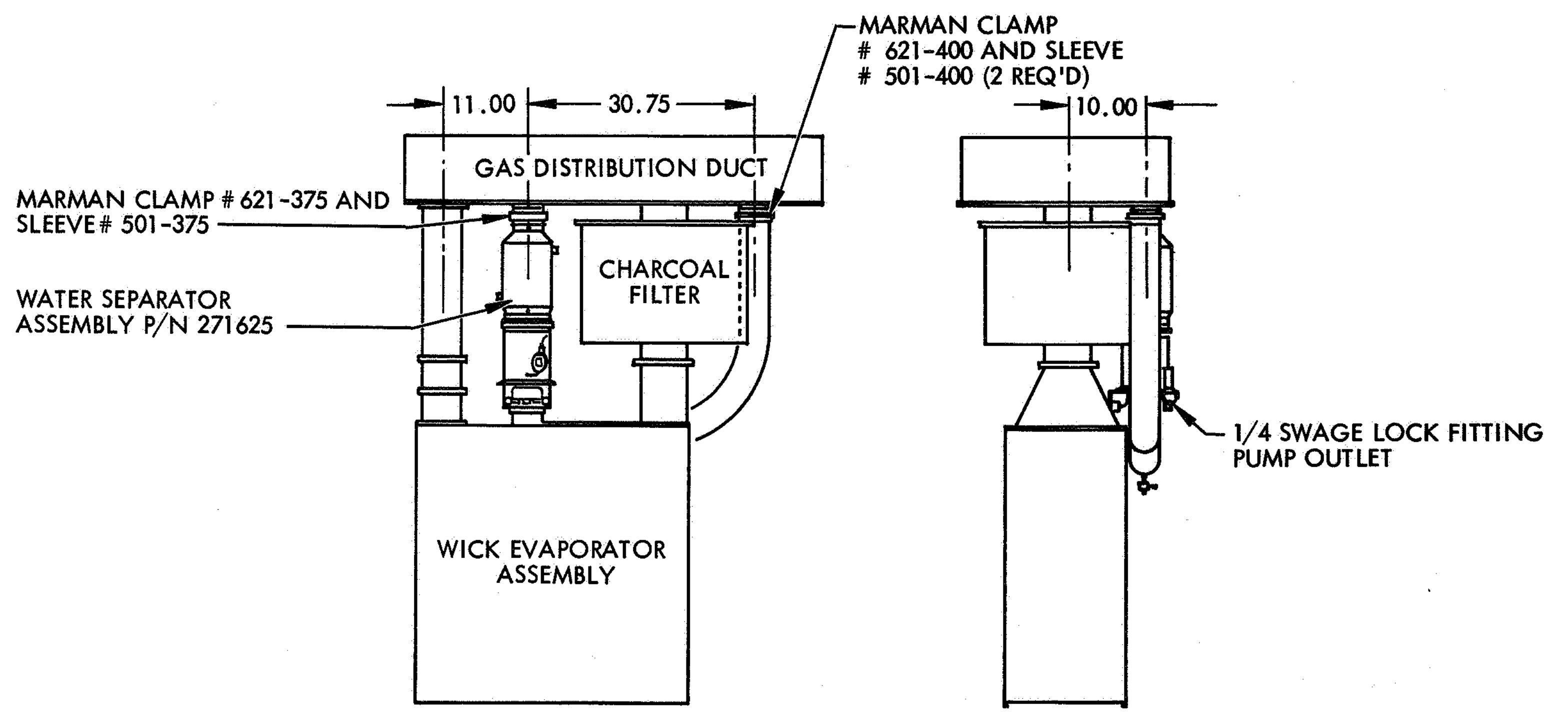

Fig. 4 - Installation of the Humidity Control System in the McDonnell Douglas Potable Water System

TEST PROGRAM FOR ZERO GRAVITY HUMIDITY CONTROL SYSTEM

A five-phase test program was conducted, with the humidity control unit integrated into the McDonnell Douglas potable water reclamation system for the last three phases. Phase I was a 60-day reliability test at LMSC on the major components of the water delivery system. Phase II was an acceptance test of the unit at LMSC. Phase III was a series of short closed loop tests, at McDonnell Douglas, of the integrated water separator and urine reclamation system at one atmosphere. Phase IV was a 4-day open loop test at 0.5 atmosphere using four subjects in a closed environment. Phase V was the 60-day open loop test with four subjects at 0.5 atmosphere in a closed environment.

Phase I - Reliability Test of Water Delivery System Components

A reliability test was conducted using a hydrophilic sump, ΔP switch, solenoid valve and a water pump. This test was conducted to determine the reliability of the components to be used during the 60-day manned test. The test simulated a water separator receiving a four man load of atmosphere condensate and urine. The test apparatus is shown in Figure 5. The test was conducted by flowing 0.1 gal/hr of water into a container with a single sump installed in its base to simulate the installation in the water separator. The ΔP switch sensed the pressure difference across the sump and operated a pump and solenoid valve to remove the water from the sump area. The test was initiated on 7 July 1967 and ran continuously for 65 days. During this test, the sump screen had to be cleaned four times. The clogging occurred at approximately equal intervals throughout the 65 days. Analysis of the material on the sump indicated that it was silicone grease which was probably a contaminant in the test plumbing. The pump was initially run at 4 volts; however, after 40 days of operation the voltage had to be increased to 6 volts to pump the same volume of water. This was attributed to a reduction in speed due to wear in the pump motor bearings.

Phase II - Acceptance Test

The acceptance test on the humidity control system was performed at LMSC on September 20, 1967, in the presence of C. Saunders of the NASA Langley Research Center. At the time of the acceptance test the Stewart Warner heat exchanger to be used in the system had not been received. Thus, an identical heat exchanger, which was used on the initial evaluation testing phase of the zero gravity humidity control system program, was substituted. The heat exchanger and water separator with the newly developed water delivery unit were installed in the test apparatus developed for the previous humidity control system evaluation program. This test equipment is described in NASA CR 66543 and shown in Figure 6. Gas circulation through the unit was provided by the fan used in the initial evaluation system. Each of the required performance points was established and data taken to confirm that the new system met the requirements. Performance data are compared with requirements below.

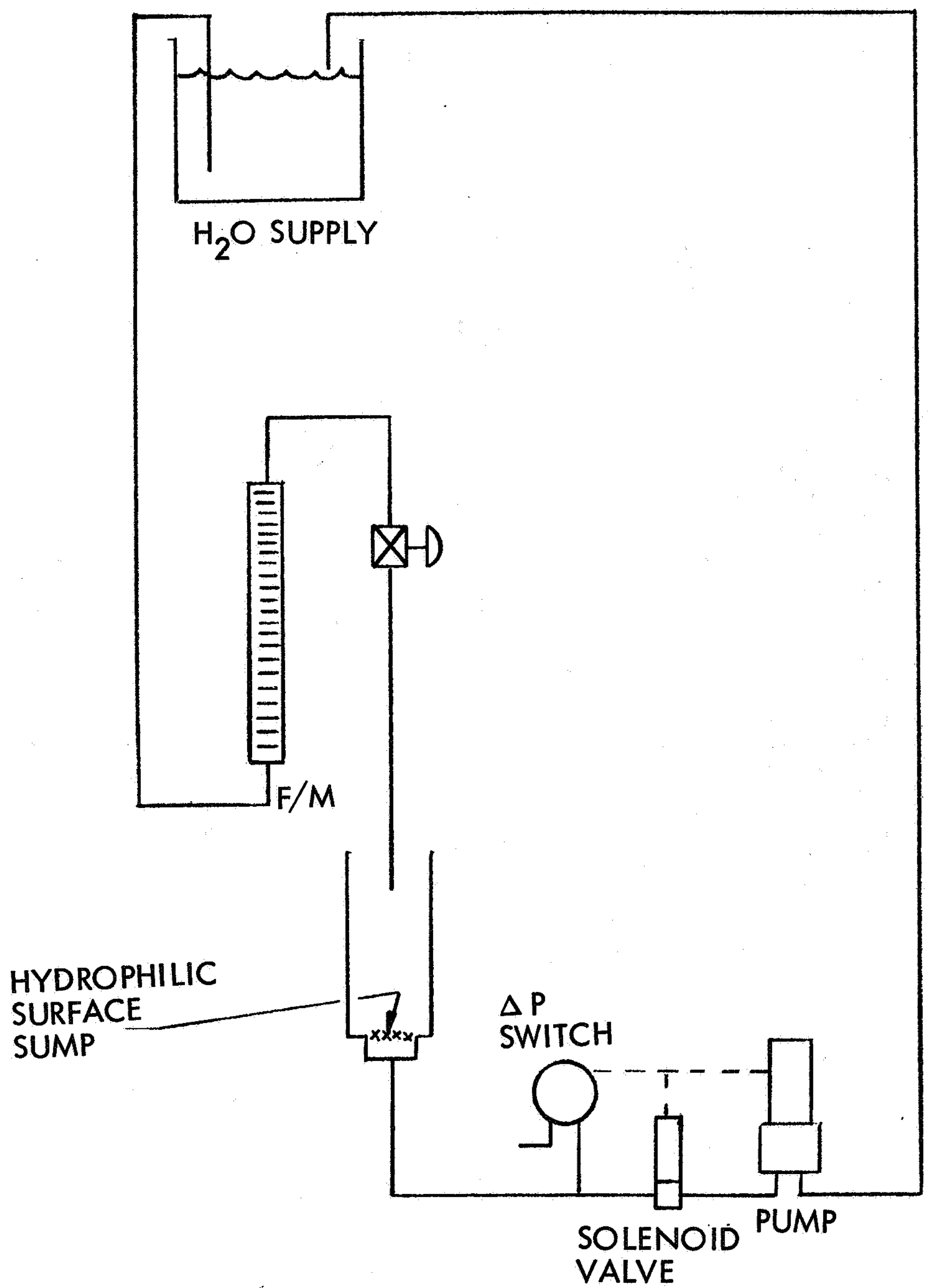

Fig. 5 - Schematic of Phase I Reliability Test

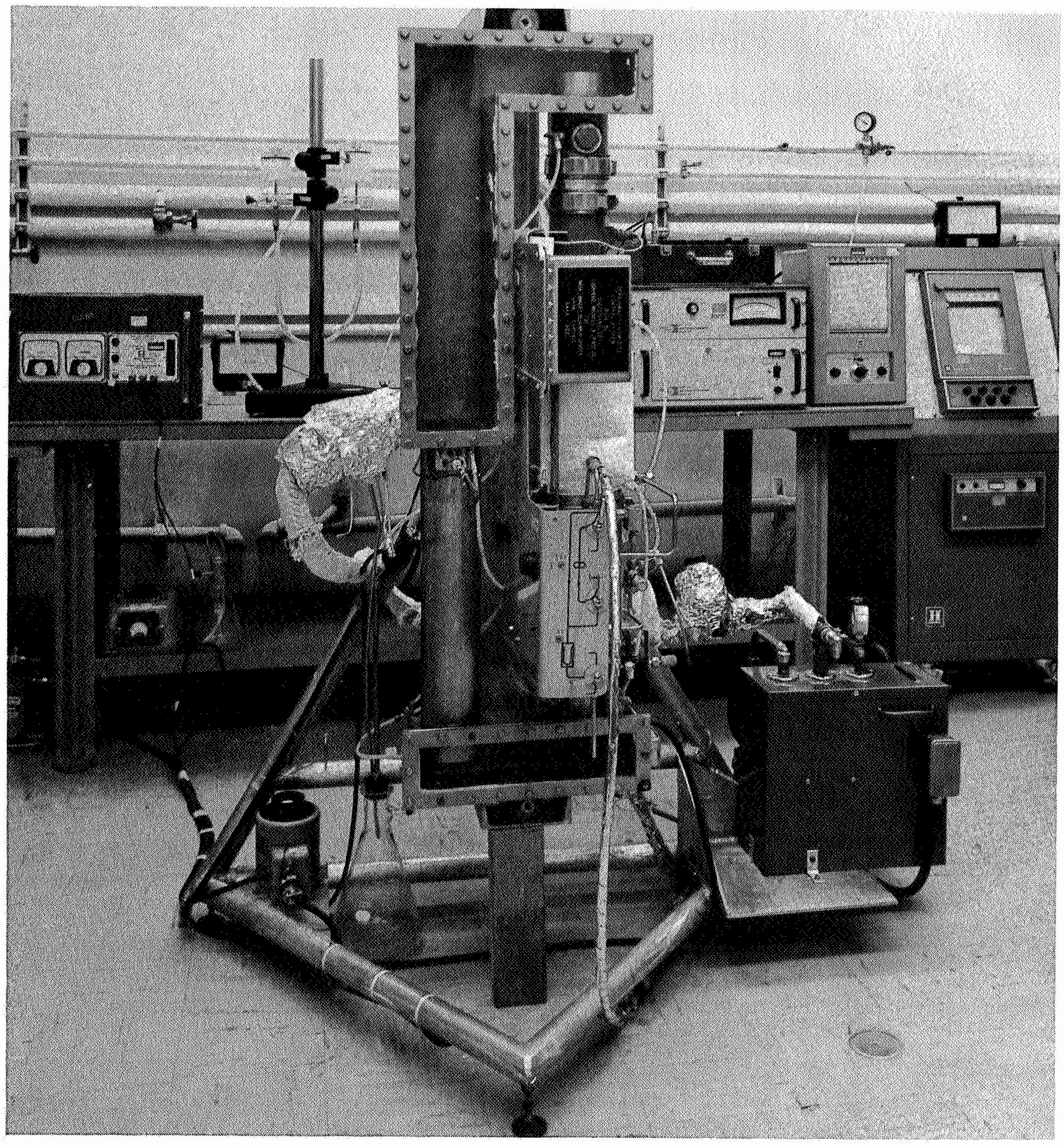

Fig. 6 - Acceptance Test Apparatus

Water Separator and Water Delivery System

Water separator pressure drop @ 60 cfm, 1 atmosphere

Measured	1.28 in. H_2O
Allowable	1.32 in. H_2O

The water delivery system extracted all water separated by the humidity control system and delivered it automatically to a reservoir at approximately space cabin atmospheric pressure.

Heat Exchanger

@60 cfm, 1 atmosphere gas side and 270 #/hr coolant side

Measured Effectiveness	92.5%
Allowable	92.0%
Measured Gas Side ΔP	0.09 in. H_2O
Allowable Gas Side ΔP	0.18 in. H_2O
Measured Liquid Side ΔP	0.88 psi
Allowable Liquid Side ΔP	1.0 psi

Complete System

@7.4 psia, 28 volts

Measured Fan Flow	130 cfm
Required Fan Flow	110 cfm

@7.4 psia, 60 cfm 20#/day or greater water flow

Measured Separation Efficiency	100%
Allowable Separation Efficiency	96%
Separation Efficiency	$\frac{\text{(water in - water out)}}{\text{water in}}$

The above tests satisfied the performance requirements of paragraph 5.6 of NASA Specification L-6021, dated 9 July 1965.

Phase III - Closed Loop Test at One Atmosphere

The purpose of Phase III was to integrate the LMSC unit into the McDonnell Douglas system (Figure 4), and to check its electrical and pressure drop compatibility. This was accomplished during a closed loop evaluation of the gas evaporation urine reclamation system. The system was operated with the gas loop closed so that the effluent of the water separator was directed back to the wicks of the evaporation unit. No cabin atmosphere and thus no humidity condensate was processed during this test. The urine reclamation system was operated at an accelerated urine introduction rate, approximately twice the design rate during this test. During this phase the conditions of operation were: gas flow rate = 80 cfm, water separator gas inlet temperature =37°F and coolant flow rate = 2.8 gpm through the condensing heat exchanger. The test of the LMSC unit was conducted in the four periods described below. The unit was operated continuously during the third and fourth period with a measured water separation efficiency greater than 96%.

Period 1 Operating Time - 146 hours 15 min - Operation was initiated at 11:45 on 20 January 1968 and continued until 14:00 on 26 January 1968 at which time the system was shut down. A total of 19.7 liters of condensate was delivered by the system.

Operation was initiated with all three sumps open; however, it was determined that all water was being withdrawn from the lowest sump (orientation of the unit was slightly off vertical) and after three hours of operation the two sumps not withdrawing water were closed. During this test period problems occurred with the electrical supply to the unit due to tripping of a circuit breaker caused by some of the simulator equipment operating on the same circuit. This power failure caused the condensate pump and solenoid valve to stop operating and allowed water to collect in the unit and ultimately pass through the hydrophobic cone. A total of 1.85 liters of water was collected in the duct downstream of the water separator.

On 27 January 1968, the sumps were removed and examined. The operating sump was found to be covered with a waxy material and with fibers. The fibers were finer than the sump screen wires and appeared to be approximately 1/8 in. in length. The waxy material was extracted with chloroform and analyzed. Infrared analysis indicated it to be 80 to 90% organic, a complex mixture of esters with slight indications of cellulose acetate. The fibers were not analyzed.

Period 2 Operating Time - 16 hours 15 min - Operation of the unit was again initiated with new sumps at 17:15 on 29 January 1968 and continued until 09:30 on 30 January 1968. During this period 5.9 liters of condensate were collected and delivered by the unit. The electrical supply circuit breaker again tripped during this test period allowing the water to build up in the unit and 1.5 liters of water passed through the hydrophobic cone.

Period 3 Operating Time - 48 hours 15 min. - Operation of the unit was initiated again at 16:15 on 31 January 1968 and continued until 16:30 2 February 1968. During this period 15.7 liters of condensate were collected and delivered by the unit. Following this test period 0.66 liter of water was found in the duct downstream of the water separator. This indicates a water separation efficienty of 96% during the test period with an average condensate collection rate of approximately 17.4 lb /day.

Period 4 Operating Time - 12 hours 30 min.- Operation was initiated at 01:00 on 3 February 1968 and continued until 13:30 on 3 February 1968. During this period 3.7 liters of condensate were collected and delivered by the unit. No water was found in the duct down stream of the water separator, which indicates a separation efficiency of 100%. This was the last operation in the closed loop mode.

Phase IV - Open Loop Test at 0.5 Atmosphere Using Four Subjects in a Closed Environment

This test was conducted in an open loop mode; i.e., humidity and urine were reclaimed. The test was initiated at 18:00 on 5 February 1968 and continued until 12:00 on 9 February 1968. No problems were encountered during the test period. An estimated 36 liters of condensate were produced (based on assumed 4-man urine and sweat rates) and approximately 0.10 liter of water was found in the duct downstream of the water separator at the conclusion of the test. This indicated an average water separation efficiency of 99.83%.

Phase V - Open Loop 60-Day Test at 0.5 Atmosphere Using Four Subjects in a Closed Environment

The unit was reinstalled in the McDonnell Douglas simulator after the phase IV post-test examination. The 60-day test began on 19 Feburary 1968 at 18:00. The following section briefly describes the results of this test. The detailed observations made during the test are presented in Appendix B.

The water separator was checked out, primed and turned on nine hours before the test began. The unit was operated with one sump valve open and two sump valves closed, under the following approximate conditions:

Coolant flow through the condensing heat exchanger:	2.8 gpm
Coolant inlet temperature:	37°F
Coolant outlet temperature:	38°F
Gas flow through unit:	80 cfm
Water separator gas inlet temperature:	37°F

Δ P across unit: 0.6 in. H_2O

Cabin pressure: 0.5 atmosphere

The unit operated satisfactorily with no problems encountered for the first 21 days of the test. During this period the water separation efficiency was 100%. On the 23rd day, of the test, LMSC was notified that the subjects had reported that the solenoid valve was not cycling (the solenoid valve should cycle on and off during normal operation). This condition had existed for two days. The subjects were then instructed to switch to another sump and to replace the two inactive sumps. Following this replacement, the unit was still not operating properly and it was determined that the differential pressure switch had failed. The differential pressure switch was replaced by the crew in the chamber at this time along with three new sumps. During this repair period the gas flow to the LMSC unit was diverted to an alternate condenser.

Examination of the failed differential pressure switch revealed that the diaphragm had developed a small leak. The switch was returned to the vendor who reported that the diaphragm material was defective.

The sumps removed from the unit were subjected to laboratory analysis. The material trapped on the hydrophilic surface was qualitatively analyzed by infrared and emission spectroscopy, and chemical methods. The results of these analyses are shown in Appendix C. A photograph of this material is shown in Figure 7. The material on the sumps was primarily from the gas evaporation urine reclamation system wicks. It was concluded that even though the sumps showed considerable blockage, the problem was due to the failed differential pressure switch. Because McDonnell Douglas personnel wanted to obtain water samples from their alternate condenser, it was left operating from the 24th to the 31st day of the test at which time the LMSC system was restarted. The LMSC unit continued to operate satisfactorily with a water separation efficiency of 100%.

On the 37th day of the test, McDonnell Douglas personnel switched from the LMSC unit to the alternate condenser because they suspected that the heat exchanger in the LMSC unit was leaking Coolanol into the potable water supply. The heat exchanger was removed and replaced by the crew in the chamber with a new heat exchanger, supplied by NASA, which was leak checked prior to installation. The heat exchanger removed by the crew was pressure checked and was found to have no leaks.

The LMSC unit was back on line at 18:00 on day 42; however, water was passing through the hydrophobic cone. This condition was attributed to the fact that Coolanol was spilled into the water separator during the heat exchanger change. This cleared up by 15:30 on test day 43 due to the rinsing action of water passing over the hydrophobic cone.

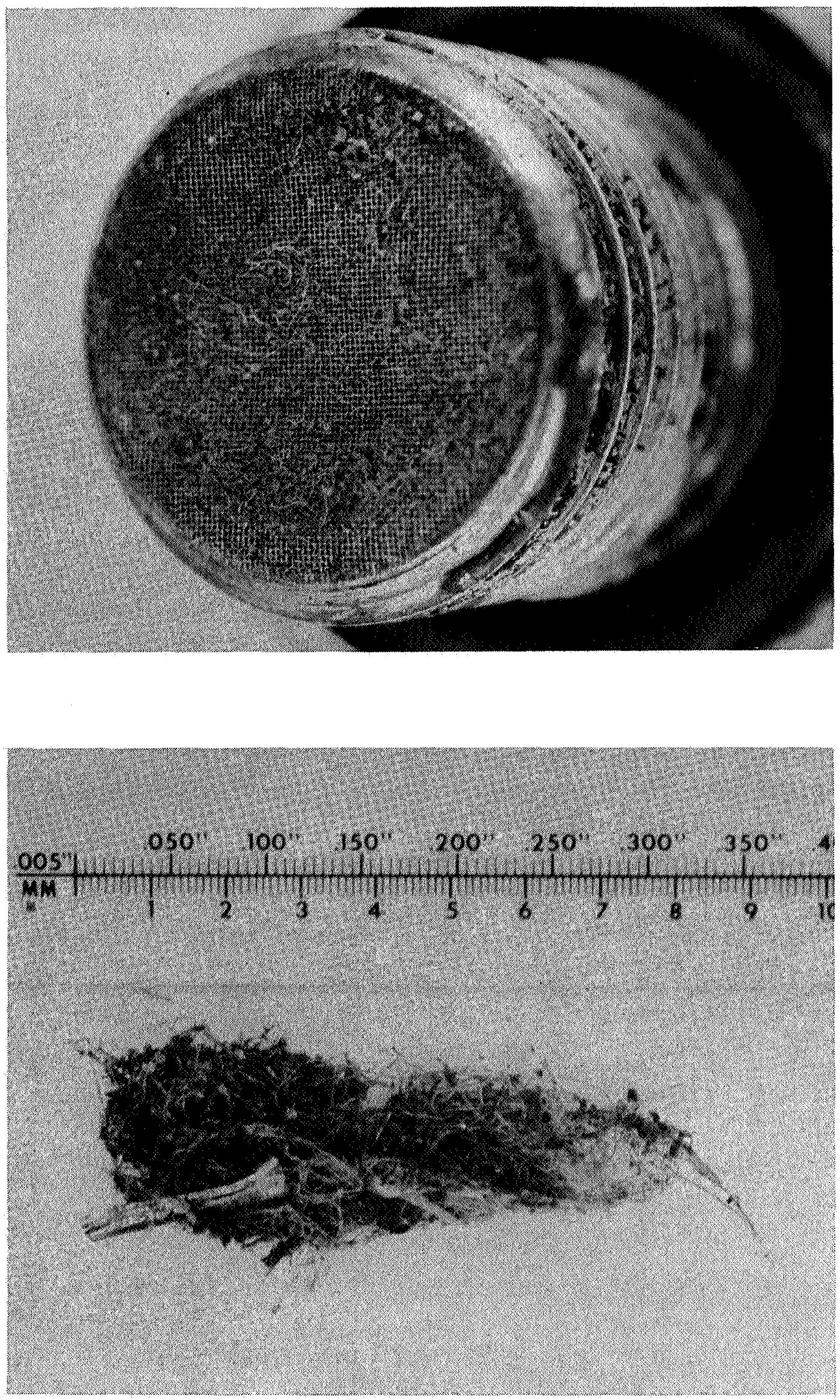

Fig. 7 - Material Trapped on Hydrophilic Sump
After 23 Days of Testing

The unit then continued to operate satisfactorily until test day 51 at which time the unit stopped operating normally and 2100 ml of water passed through the hydrophobic cone. At this time, the ΔP switch was suspected since the diaphragm in this switch was from the same lot as the previous switch and therefore it was probably defective. The switch was replaced by the crew with one which had been used in the 60-day component reliability test. Examination of the failed switch revealed that the diaphragm did leak.

Operation of the unit was continued; however, the pump water withdrawal rate had diminished so the pump voltage was increased to 10 volts. The unit was operating normally by 14:30 on test day 51 and continued to operate satisfactorily with a 100% water separation efficiency. The system was operating satisfactorily at the conclusion of the 60-day test.

The 60-day test was ended on 19 April 1968 at 07:30. The water separator was removed from the chamber immediately after the conclusion of the test. The separator was then disassembled and examined. The three sumps were clean and in good operating conditions. The hydrophobic cone was quite clean, however it had a wet appearance in the small area near the base. There was no evidence of water in the duct downstream of the hydrophobic cone and no gas in the line downstream of the hydrophilic sump. The condition of the cone, sumps, and water separator interior can be seen in Figure 8.

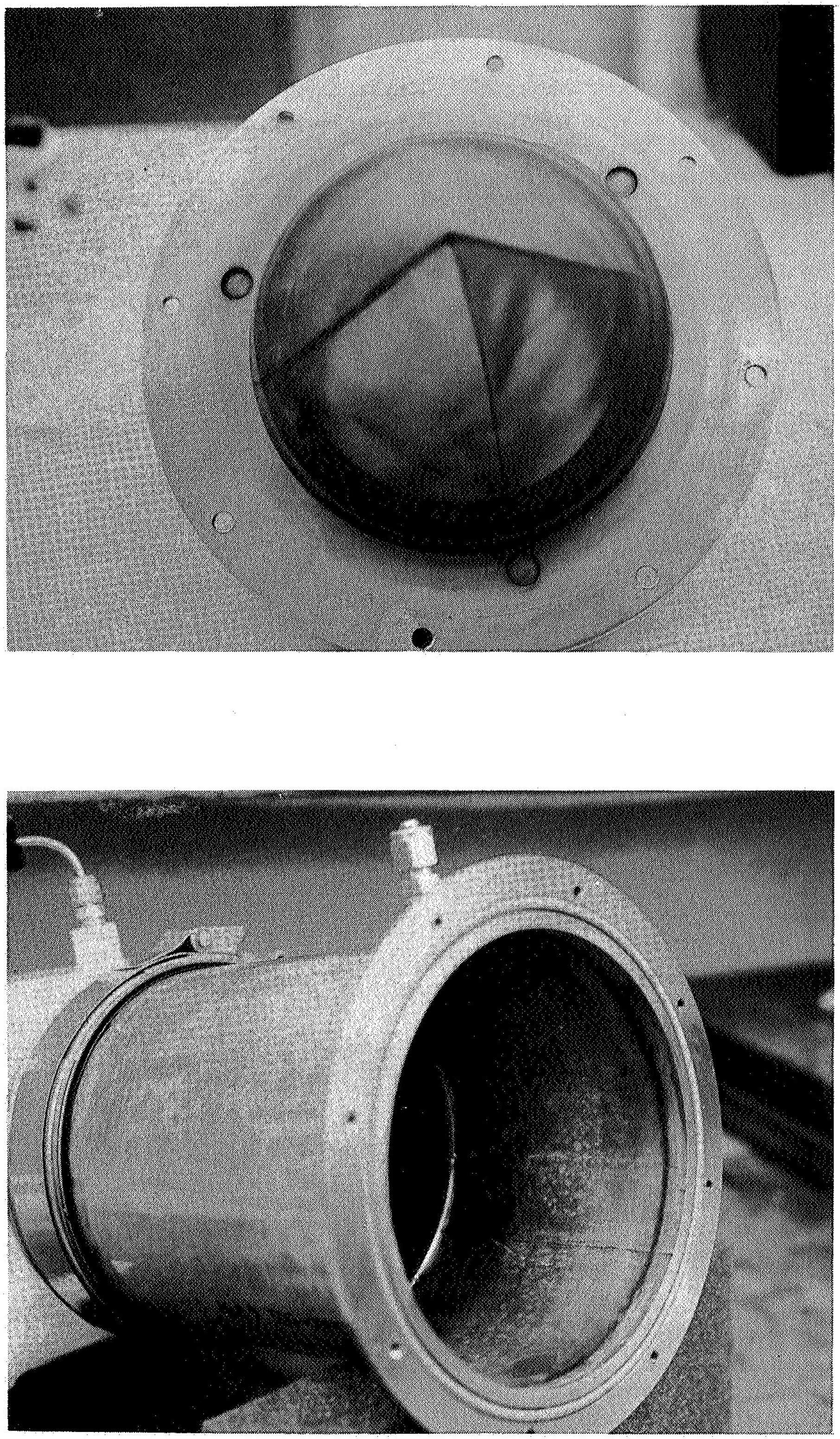

Fig. 8 - Condition of the Humidity Control System Components After the Sixty Day Test

CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are based on the 60-day manned test of the Lockheed humidity control system installed in the McDonnell Douglas space station simulator.

The water separator operated satisfactorily for 60 days with a water separation efficiency of 99% or better during the time of normal operation. The in-flight maintainability of the unit was very good. The maintenance and replacement of sumps was done by the untrained test subjects, using no special tools and very little verbal instructions. These tasks were accomplished in a short time allowing the unit to stay on line and operating.

The results of the test were extremely favorable, however, a few areas where design improvement should be made have been identified. Also, additional system integration aspects become apparent as a result of the test results. These items are described below.

Performance Instrumentation

Additional instrumentation to provide a warning against clogged sumps or failure of the water withdrawal system would be desirable and could have eliminated the few occasions when water passed through the hydrophobic cone. Water breakthrough, when the delivery system fails, is due to the increased pressure forcing the water through the cone as the water accumulates and reduces the open area available for gas flow. Therefore, an increase in ΔP across the hydrophobic cone could be used to signal a failure alarm.

Filtration

In application of this system in the LMSC two-gas regenerative life support system (TGRLSS), a fine metal screen filter is employed up stream of the fan that supplies the gas flow. In the McDonnell Douglas system the filtration was accomplished by filter material at the outlet of the charcoal canister. It appeared from the test results that this filtration was inadequate and therefore a finer filter media such as that used in the TGRLSS, should be used in future testing. It would be desirable to locate this filter immediately up stream of the condensing heat exchanger.

Differential Pressure Switch

The two differential pressure switch failures that occurred during the test were due to defective diaphragms. The Viton material that was used was probably not the best choice for a diaphragm because of its tendency to cold set. Therefore, it is recommended that other diaphragm materials be considered for this switch. It would also be desirable to use a switch with a more rugged internal construction.

Water Pump

It was necessary to increase the voltage to the pump motor near the end of the test. The loss in pump performance was attributed to a loss of rpm at a fixed voltage rather than pump gear wear. The increased torque requirements were probably due to an increase in friction in the motor bearings as the test progressed. Therefore, it is recommended that a pump motor be used whose rpm is not as sensitive to torque.

APPENDIX A

DETAILED OPERATING PROCEDURES

Equipment required for operation of the Zero Gravity Humidity Control System

1. 28 VDC Power Supply (10 AMP capacity)
2. Refrigeration system that will provide a continuous flow of 35°F coolant to the condensing heat exchanger
3. Gas flow indicator

Preparation for Use and Checkout

Step	Procedure	Normal Indications	Notes
1	Turn pump and solenoid valve switches to off position	Off position indicated on control panel	
2	Connect system to interface equipment		Install system in test fixture
	a. Connect 28 VDC power supply. Ref-Schematic SK 30885	Meter on power supply to read max 28 V	
	b. Connect coolant lines to heat exchanger		Check for leaks
3	Check cabling and fuses	Connector in place and secure	Connector on differential pressure switch
4	Tighten and leak check all gas and water lines		Pressurize max 5 psi with dry nitrogen and check pres.dec.

Step	Procedure	Normal Indications	Notes
5	Close all sump valves	Turned clockwise to stop	Valves are metering valves and should be closed finger tight only
6	Close charge valve	Turned clockwise to stop	Valve is a metering valve and should be closed finger tight only
7	Instrumentation ports		If instrumentation is not used all unused ports should be plugged and leak checked.

Operation

The Humidity Control System controls for normal operation are all contained within and on the unit itself. The function and locations of each control and valve are described below.

Sump Valves - These valves are located in front of the sump plate on the separator unit. There is one valve for each sump. These valves are used during the sump screen wetting procedure and for regulating the liquid flow from the water separator to the storage tank.

Charge Valve - This valve is used to emit water into the water recovery system to wet the sumps screen prior to system use.

Differential Pressure Switch - This switch is located on the side of the separator unit. The switch senses the ΔP across the hydrophilic sump (gas side to liquid side). When there is sufficient ΔP the switch activates the pump which removes the liquid in the sump.

Operating Procedures

Step		Procedure	Normal Indications	Notes
1	Wet Sump Screens	Open charge valve. Open one sump valve approximately 1/4 turn ccw. Let sufficient water flow to wet screen and close valve. Follow the same procedure for all three sumps.	Sump outlet tubes are filled with gas-free liquid.	
2	Prime Pump	Set solenoid valve switch in manual open position and let sufficient liquid flow to fill pump cavity. Set solenoid valve switch in automatic position.	Liquid flow in reservoir	Pump should not be run dry
3	ΔP Switch	Set ΔP switch to 4 inches of water effective at the sump	Read directly on switch adjustment screw	
4	Heat Exchanger	Flow coolant through H-X at desired temperature.	H-X body will become cool to the touch	Check inlet and outlet connections are correct for counter flow operation
5	Pump	Set pump switch in auto position	Auto position on control panel	

APPENDIX B

STATUS REPORTS OF THE ZERO GRAVITY HUMIDITY CONTROL SYSTEM DURING THE 60-DAY TEST

STATUS REPORT NO. 1

Date 20 February 1968
Test Day 2

The Zero Gravity Humidity Control System was reinstalled in the McDonnell Douglas simulator after the short term post-test examinations with the silver ion generator immediately downstream of the water pump.

Prior to chamber pump down on 19 February 1968 the water separator was checked out, primed, and started, functioning at 9:10 am under the following conditions using one sump.

Cooling flow through the condensing heat exchanger: 2.8 gpm

Coolant inlet temperature: 37°F

Coolant outlet temperature: 38°F

Gas flow through unit: 82 cfm

Gas inlet temperature: 37°F

Gas outlet temperature: 38°F

Δ P across unit: 0.75 inch H_2O

Cabin pressure: one atmosphere (cabin door open)

Unit operating in open loop mode (cabin humidity only, no urine)

At approximately 9:20 the sump started sucking gas and there was no water flow at the exit port of the silver ion generator. The silver ion generator was removed, and the unit reprimed and turned on. In this mode the unit functioned normally. The silver ion generator was removed and reinstalled upside down. The water separator was reprimed and turned on. In this mode the unit functioned normally.

The chamber pump down was started at 4:15 pm. The subjects entered the chamber at 6:00 pm and the 60-day test started.

At 7:00 pm the operating sump showed signs of being partially plugged. The ΔP across the unit rose from 0.6 in. H_2O to 0.9 in. H_2O. The test subject in the chamber was notified and requested to change to another sump, this was accomplished and the ΔP dropped from 0.9 in. to 0.6 in. H_2O; the unit continued to function normally for the next two days. The data recorded during test days 1 and 2 are shown in Table 1.

Suspect sump plugging was due to lint blown off new wicks installed in the urine reclamation system.

TABLE 1
PERFORMANCE DATA

Date 20 February 1968
Chamber Pressure 373-368 mm Hg
Chamber Temperature 78°F - 81°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flow (CFM)
9:30 A.M.	38	39	47	44	0.6	81
10:30	35	37.5	51	43	0.6	
11:30	38.5	40	53	44	0.6	
12:30 P.M.	34	37	52	42	0.6	
1:30	36	38	51.5	46	0.6	
2:30	34.5	36.5	50.5	42.5	0.6	
3:30	34	36	48	42	0.6	
4:30	39	40	51	46	0.6	81
Date 2-21-68						
9:30 A.M.	34	36	Dew Point Temp. not available (NA) due to over heating of unit in simulator		0.6	81
10:30	38	40			0.6	
11:30	34	36			0.6	
12:30 P.M.	34	36			0.6	
1:30	34	36			0.6	
2:30	35	37	48	41	0.6	
3:30	35	36.5	50	44	0.6	81

STATUS REPORT NO. 2

Date 29 February 1968
Test Day 10

The Zero Gravity Humidity Control System installed in the McDonnell Douglas simulator for the 60-day manned test was functioning normally as of 29 February 1968. McDonnell Douglas records showed 40 liters of urine were processed as of this date. Cabin humidity was maintained between 31-33% R.H. The dew point temperature instrumentation was not available at all times due to an overheating problem of the instrument located in the simulator. This instrument has been put on an on-and-off duty cycle.

No water was collected in the down stream water drop out tank, indicating a 100% removal efficiency for the unit. The data taken on 29 February 1968 are shown in Table 2.

TABLE 2
PERFORMANCE DATA

Date 29 February 1968
Chamber Pressure 358 mm Hg
Chamber Temperature 79°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
11:00 A.M.	35	37	48	39	0.6	80
12:00 NOON	35.5	37.5	49	40	0.6	80
1:00 P.M.	35	37.5	NA	NA	0.6	80
2:00 P.M.	36	39	49	40	0.6	80
3:00 P.M.	36	38	NA	NA	0.6	80
4:00 P.M.	35	37	NA	NA	0.6	80
5:00 P.M.	35	37	NA	NA	0.6	80

STATUS REPORT NO. 3

Date 6 March 1968
Test Day 16

The unit was functioning normally. The original sump showed no sign of plugging. As of 6 March 1968, 67 liters of urine have been processed. The data recorded during test day 16 are shown in Table 2.

TABLE 3
PERFORMANCE DATA

Date 6 March 1968
Chamber Pressure 365.4 - 366 mmHg
Chamber Temperature 78°

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
10:00 A.M.	35	38	46	40	0.6	80
11:00 A.M.	34	36.5	47	38	0.6	80
12:50 P.M.	35	36.5	47	38	0.6	80
1:00 P.M.	35	37	47	38	0.6	80
2:00 P.M.	34	36	49	39	0.6	80
3:00 P.M.	36	36	48	38	0.6	80
4:00 P.M.	35	37	48	38	0.6	80
5:00 P.M.	35	37	48	38	0.6	80

STATUS REPORT NO. 4

Date 13 March 1968
Test Day 23

On 11 March 1968 the subjects in the chamber reported that the water separator had stopped clicking. (Solenoid valve clicking on and off is subject's audio indication that unit is operating normally.) LMSC was not notified of this condition at this time.

On 13 March 1968, 9:30 am, LMSC was told of the conditions described above. Working with a subject in the chamber through the voice communication system, it was determined that the working sump was plugged and the unit was in the solenoid valve-open pump-on mode, and had been since 11 March 1968. At 10:00 am the subject closed the working sump and turned the unit off. The subject checked and found water in the ΔP switch line which he drained. The subject then turned the unit on and opened No. 3 sump. By 10:30 the unit was operating normally using No. 3 sump. The subjects reported that there was no water in the dropout duct, indicating that the unit was operating at 100% efficiency.

The plugged sumps No. 1 and No. 2 were removed and replaced at 4:00 pm on 13 March 1968. During the sump change, one plastic sump line was replaced due to cross-threading of the fitting nut on sump No. 2. At 5:00 pm, the unit was operating normally. The data taken on 13 March 1968 are shown in Table 4.

TABLE 4
PERFORMANCE DATA

Date 13 March 1968
Chamber Pressure 357 - 364 mm Hg
Chamber Temperature 78°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point(°F)	Water Separator Outlet Dew Point(°F)	Water Separator Δ P(in. H_2O)	Water Separator Gas Flows (CFM)
11:00 A.M.	30	NA	NA	NA	0.6	80
12:00 NOON	30.5	NA	NA	NA	0.6	80
1:00 P.M.	31.5	NA	NA	NA	0.6	80
2:00 P.M.	NA	NA	NA	NA	0.6	80
3:00 P.M.	32	NA	46	38	0.6	80

STATUS REPORT NO. 5

Date 22 March 1968
Test Day 32

The water recovery system was switched from the LMSC unit to the McDonnell Douglas alternate unit on 14 March 1968. The LMSC unit was not operating normally.

20 March 1968

10:15 am - Water recovery was switched from McDonnell Douglas unit to LMSC unit.

11:15 am - The No. 2 sump was opened and the unit appeared to be operating normally, the ΔP was 0.55 in. H_2O and the air flow was 80 cfm.

12:30 pm - The ΔP rose to 0.75 in. and it was discovered that the valve between the unit and the water sterilization system was closed. This valve was opened and the unit withdrew water from the sump area. The ΔP dropped to 0.6 in. H_2O.

12:35 pm - The unit was operating normally with no water in the drop out duct.

4:30 pm - The unit was removing water but the solenoid valve remained open and the pump remained on. A check of the line to the ΔP switch revealed that no water was present.

5:00 pm - The unit was operating normally on No. 2 sump.

REMARKS:

When working on the unit a certain amount of water gets dislodged in the heat exchanger and flows to the sump area. The unit seems to work normally after this for about two hours.

21 March 1968

9:30 am - Approximately 500 cc of water was removed from the drop out duct. The valve on the working sump was not open enough to take water and therefore water passed through the hydrophobic screen. The sump valve was opened and the system automatically withdrew the water.

11:00 am - The unit was not operating normally. Plugged sumps or a defective ΔP switch was suspected. Changes could not be made until 1:00 pm, thus the unit ran in the solenoid valve-open and pump-on mode.

1:00 pm - Three sumps and the ΔP switch were changed and the unit was flushed out with 500 cc of distilled water. See Appendix C for analysis of sump residue. Water was found in-line on the gas side of the ΔP switch. The unit was reassembled and put back on line at 1:50 pm. The unit was operating normally.

4:30 pm - The unit was operating normally and 124 liters of urine have been processed to date.

22 March 1968

9:00 am - At 2:00 am, 22 March 1968, unit passed 2300 ml of water to the drop out duct. The sump valve was not opened enough and the unit couldn't take the water fast enough. The valve was opened from 1/4 turn open to 1/2 turn open and the unit has operated normally from 2:10 am to 9:00 am.

11:30 am - The unit was operating normally and 127 liters of urine have been processed to date. Data taken on 20 March through 22 March are shown in Table 5.

TABLE 5
PERFORMANCE DATA

Date 20 March 1968
Chamber Pressure 363 mm Hg
Chamber Temperature 78°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
11:30 A.M.	34	NA	46	38	0.58	80
12:30 P.M.	33	NA	45	37	0.75	80
1:30 P.M.	33	NA	43	36	0.6	80
2:30 P.M.	33	NA	44	40	0.6	80
3:30 P.M.	33	NA	45	37	0.6	80
4:30 P.M.	33	NA	44	37	0.6	80

Date 22 March 1968
Chamber Pressure 362 mm Hg
Chamber Temperature 75°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
9:30 A.M.	31	NA	44	37	0.6	80
10:30 A.M.	31	NA	44	38	0.6	80
11:30 A.M.	31	NA	45	38	0.6	80

NOTE: Thermocouple readings are being disturbed due to work on instrumentation readout consoles.

STATUS REPORT NO. 6

Date 2 April 1968
Test Day 43

1 April 1968

On 27 March 1968 McDonnell Douglas switched from the LMSC unit to the McDonnell Douglas condensing system to obtain a water sample from their condensing unit. McDonnell Douglas suspected that the LMSC heat exchanger was leaking Coolanol into the potable water supply. On 1 April 1968 at 4:00 pm the heat exchanger in the LMSC unit was removed and replaced with a new heat exchanger supplied by NASA, which was leak checked prior to installation. The LMSC unit was back on line and operating normally at 6:00 pm on 1 April 1968. The removed heat exchanger was pressure checked at 50 psig with dry nitrogen and found to have no leaks.

2 April 1968

The unit operated normally from 6:00 pm on 1 April 1968 until approximately 8:00 am on 2 April 1968. The unit stopped clicking and passed approximately 2000 ml of H_2O to the drop out duct. The ΔP switch was adjusted to 7 in. H_2O. The unit appeared to function normally until 2:00 pm. The ΔP across the unit slowly rose to 0.75 in. H_2O and passed 50 cc of H_2O to the drop out duct. At 3:00 pm a subject opened the sump valve 1/4 turn to 3/4 turn open. The unit removed the water build-up and the ΔP dropped to 0.6 in. The unit was operating normally at 3:30 pm.

STATUS REPORT NO. 7

Date 10 April 1968
Test Day 51

9 April 1968

5:00 pm. - The silver ion generator was reinstalled in separator outlet line.

10 April 1968

8:30 am. - The unit passed 2100 ml H_2O to the drop out duct. The subject changed to No. 3 sump. The unit was operating normally at 8:35 am.

At approximately 12:30 pm, the unit malfunctioned and passed 100 ml H_2O to drop out duct. The subject found H_2O in line on the gas side of the Δ P switch. The Δ P switch and sumps were changed at 2:00 pm. The Δ P switch was set at 8 in. of H_2O and the voltage was increased on the pump to 10 volts. The unit was back on line and was operating normally at 2:30 pm. A total of 236 liters of urine have been processed to date. Data taken on 10 April 1968 are shown in Table 6.

TABLE 6
PERFORMANCE DATA

Date 10 April 1968
Cabin Pressure 362 - 368 mm Hg
Cabin Temperature 77°F

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
10:00 A.M.	35	39	47	39	0.68	80
11:00 A.M.	34	38	48	39	0.68	80
12:00 NOON	34	36	48	39	0.70	80
1:00 P.M.	35	38	48	38	0.74	80
2:00 P.M.	34	38	47	38	0.78	80
3:00 P.M.	33	36	47	37	0.65	80

STATUS REPORT NO. 8

Date 19 April 1968
Test Day 60

18 April 1968

10:30 am. - To date 271 liters urine have been processed.

The unit has been operating normally since last visit at 100% water separation efficiency. Temperature data were not available because the temperature readout equipment was tied up by the test engineer who was trying to start up the Sabatier.

19 April 1968

The test ended and the subjects came out of chamber at 7:30 am. Total urine processed was 276 liters.

10:00 am. - The unit was removed from the simulator and disassembled. The sumps appeared to be clean. The hydrophobic screen was wetted in several places about 1/2 inch above the base. There were two sections about 1/4 inch wide by 3 inches long one above the other running around the base. A slight discoloration of the hydrophobic cone was observed around the base of the cone. This condition was noticed after the five day test. The inside of the barrel appeared to be clean (no mold or debris). The working sump line was full of water with no gas bubbles present. The drop out duct down stream of the unit was dry when the unit was removed. Data for test day 59 and 60 are shown in Table 7.

TABLE 7
PERFORMANCE DATA

Time	Water Separator Inlet Gas Temp. (°F)	Water Separator Outlet Gas Temp. (°F)	Water Separator Inlet Dew Point (°F)	Water Separator Outlet Dew Point (°F)	Water Separator Δ P (in. H_2O)	Water Separator Gas Flows (CFM)
9:00 A.M.	NA	NA	46	37	0.7	80
10:00 A.M.	NA	NA	48	40	0.7	80
11:00 A.M.	NA	NA	46	37	0.7	80
1:00 P.M.	NA	NA	48	37	0.7	80
2:00 P.M.	NA	NA	46	37	0.7	80
3:00 P.M.	35	39	46	38	0.7	80
4:00 P.M.	35	39	46	38	0.7	80

APPENDIX C

CHEMICAL ANALYSES OF SUMPS AND RESIDUES

Sump No. 1 Analysis (23 Days)

Chloroform Extraction - Negligible

Visual - Some Fibers (Cellulose)

Sump No. 2 Analysis (23 Days)

Debris on screen - see photograph in Fig. 7

Metal Content (Emission Spectroscopy)

Major:	Silicon	)	
Minor:	Aluminum	)	
	Magnesium	)	------- Typical Glass
	Boron	)	
Trace:	Copper	)	
	Chromium	)	

Chloroform Soluble Material (Infrared Analysis)

Major: Silicon oil
Trace: Hydrocarbon oil
Plasticyer (ester) indication

Residue Left After Chloroform Extraction

IR: Indicative of Rayon and Glass
Metal: Content Same as total debris

Sump Interior

Chloroform Extraction - Silicone Oil

Resume of Results

Sump No. 2 definitively contained significant amounts of silicone oil. It was found in the debris, on the screen and on the inner wall. Traces of hydrocarbon oil and an ester were also formed,in this case, primarily on the screen and in the debris.

The insoluble or fibrous portion of the debris is indicated to be primarily cellulose with a few glass fibers scattered throughout the sample.

It is estimated that the debris contains approximately 0.05-0.1% soluble organic material, and that 1-5 milligrams of silicone oil were removed from the sump walls.

Sump No. 1 was relatively clean except for a few fibers.

Sample Analysis - Day 31

Samples of Water from the System and Downstream

Solid content was determined by evaporation to dryness, then a chloroform soluable extract was made. The results are shown below.

Water Sample	mg/cc Debris	Solid	Chloroform Soluble
System	0.03	Cellulose Inorganics	*Phthalate ester
Downstream	0.02	Inorganics	Phthalate ester

Sumps

The screens were washed with chloroform and the extracted material was analyzed with results as shown below.

	Identification
(1)	Trace of organic material**
(2)	Trace of organic material**
(3)	Significant amount of Coolanol

Coolanol Analysis

Part of the compound was found to be a sebasic acid ester. Presence of a silicone is indicated by IR and emission analysis. The latter picked up major amounts of silicone.

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*This ester, detected in the water, appears to be a plasticizer from some part of the unit. Coolanol could not be detected in either sample.

**These sumps had been flushed with water prior to the chloroform wash.

LIBRARY CARD ABSTRACT

A Zero Gravity Humidity Control system was provided by LMSC for the 60-day McDonnel Douglas manned simulator test. The system was integrated with the McDonnell Douglas air evaporation potable water recovery system for urine and atmospheric condensate.

The program consisted of five parts:

- A 60-day reliability test on the major components of the water delivery system
- Acceptance test at LMSC
- A series of short closed loop tests at one atmosphere
- Short open loop manned test at 0.5 atmosphere
- The 60-day manned test

The system was operated satisfactorily throughout the 60-day test. Repairs were required midway through the test due to failure of a pressure switch and occasional clogging of the hydrophilic sumps due to carry over of particulate matter from upstream systems. These repairs were accomplished quickly by the inside crew and could have easily been carried out by an astronaut in space. The condensing heat exchanger was replaced by the crew to establish the cause of a suspected Coolanol leak. Post-removal examination and test of the heat exchanger indicated that it did not leak. At the conclusion of the test the system was operating satisfactorily with a 100% water separation efficiency.