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VAPOR COMPRESSION DISTILLATION SUBSYSTEM (VCDS) COMPONENT ENHANCEMENT, TESTING AND EXPERT FAULT DIAGNOSTICS DEVELOPMENT

FINAL REPORT

Volume I

by

L.S. Kovach and E.M. Zdankiewicz

December, 1987

Prepared Under Contract NAS9-16374

by

Life Systems, Inc.
Cleveland, OH 44122

for

LYNDON B. JOHNSON SPACE CENTER
National Aeronautics and Space Administration

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FOREWORD

The development work described herein was conducted by Life Systems, Inc. during the period June, 1984 to December, 1987. The Program Managers were Ed Zdankiewicz who completed the major portion of the program followed by Ed Mallinak completing the expert fault diagnostic development and final efforts. Technical support was provided by the following:

Personnel	Responsibility
Jeff Birkel	Electrical Software Design
David Case	Electrical Technician
James Chu	Mechanical Design and Testing
Steve Czernec	Mechanical Technician and Test Support
John O. Jessup	Electrical Hardware Design and Fabrication
Licia S. Kovach	Testing Analysis and Documentation
Earl Linaburg	Hardware Fabrication and Purchasing
Ed Mallinak	Expert Fault Diagnostics Development and Program Management
Dave Novak	Mechanical Design
Mike Prokopcak	Mechanical Design
Bob Roski	Hardware Fabrication and Purchasing
Dorothy Ruschak	Contract Administration
Franz H. Schubert	Product Technology
Lowell Wolfe	Chemical Analysis and Testing
Dan Walter	Mechanical Design
Rob Werner	Mechanical Design
Rick A. Wynveen, Ph.D.	Business Manager, Cost and Schedule Conformance
Ed Zdankiewicz	Mechanical Design, Fabrication, Testing and Program Management

The Final Report consists of two stand-alone documents. This document is Volume I. It consists of a summary of the total work effort except for the Vapor Compression Distillation Subsystem expert fault diagnostic development (Volume II).

The Final Report is submitted to the National Aeronautics and Space Administration Johnson Space Center as required by Statement of Work Task 15.2e of Life Systems, Inc.'s Program Plan, TR-471-22D, dated September 13, 1985. The Technical Monitor of the program was Mr. Don F. Price, Crew Systems Division, National Aeronautics and Space Administration, Johnson Space Center, Houston, TX.

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LIST OF ACRONYMS

C/M I	Control/Monitor Instrumentation
CTC	Compressor Test Chamber
CTS	Compressor Test Stand
DAS	Data Acquisition System
ECLS	Environmental Control and Life Support
FMEA	Failure Modes and Effects Analysis
FPTS	Fluids Pump Test Stand
JSC	Johnson Space Center
NASA	National Aeronautics and Space Administration
ORC	Orbital Replacement Component
PCM	Pressure Control/Monitor
PM	Pressure Transducer Monitor
SOW	Statement of Work
SPM	Speed/Power Monitor
TeCM	Temperature Control/Monitor
TSA	Test Support Accessories
TSC	Test Stand Controller
VCD	Vapor Compression Distillation
VCDS	Vapor Compression Distillation Subsystem
VCD2A	Vapor Compression Distillation Subsystem, Advanced Preprototype Configuration
VCD2B	Vapor Compression Distillation Subsystem, Enhanced Advanced Preprototype Configuration

SUMMARY

Vapor Compression Distillation technology for phase change recovery of potable water from wastewater has evolved as a technically mature approach for use aboard the Space Station. A program to parametrically test an advanced preprototype Vapor Compression Distillation Subsystem was completed by Life Systems for the National Aeronautics and Space Administration Johnson Space Center during 1985 and 1986.

In parallel with parametric testing, a hardware improvement program was initiated to test the feasibility of incorporating several key improvements into the advanced preprototype Vapor Compression Distillation Subsystem following initial parametric tests. Specific areas of improvement included long-life, self-lubricated bearings, a lightweight, highly-efficient compressor and a long-life magnetic drive. With the exception of the self-lubricated bearings, these improvements are now incorporated.

The advanced preprototype Vapor Compression Distillation Subsystem was designed to reclaim 95% of the available wastewater at a nominal water recovery rate of 1.36 kg/h (3.0 lb/hr) achieved at a solids concentration of 2.3% and 308 K (95 F) condenser temperature. While this performance was maintained for the initial testing, a 300% improvement in water production rate (4.1 kg/h (9.0 lb/hr) at a 316 K (110 F) condenser temperature) with a corresponding lower specific energy was achieved following incorporation of the improvements.

Testing involved the characterization of key Vapor Compression Distillation Subsystem performance factors (water production rate, water quality and specific energy) as a function of recycle loop solids concentration, distillation unit temperature and fluids pump speed. The objective of this effort was to expand the Vapor Compression Distillation Subsystem data base to enable defining optimum performance characteristics for flight hardware development.

INTRODUCTION

Unless on-board wastewater can be reclaimed, the future National Aeronautics and Space Administration (NASA) Space Station will require large quantities of potable water supplied from earth for crew use such as drinking, washing and oxygen generation by electrolysis. The recovery of potable water from urine and hygiene wastewaters will minimize the expensive launch weight and resupply penalties associated with this requirement.

Vapor Compression Distillation (VCD) has been shown to be an optimum water recovery technique characterized by low specific energy while producing a high quality product water from projected Space Station wastewater sources.

Background

Under Contract No. NAS9-16374 to the NASA Johnson Space Center (JSC), Life Systems, Inc. (Life Systems) has developed an advanced preprototype Vapor

Compression Distillation Subsystem (VCDS) (1).[a] This advanced preprototype was based upon a unit previously developed by Life Systems, defined as the VCD2. (2) The advanced preprototype VCDS, defined as the Vapor Compression Distillation Subsystem, Advanced Preprototype Configuration (VCD2A), is a completely self-contained, automated subsystem capable of processing wastewater at a nominal rate of 32.6 kg/day (72.0 lb/day). The mechanical subsystem package dry weight is only 101 kg (223 lb), occupies 0.49 m^3 (17.3 ft^3) and requires only 115 W electrical power. In parallel with parametric testing, a hardware improvement program incorporating a lightweight, highly-efficient compressor with an integral long-life magnetic drive was successfully completed. Tests with long-life, self-lubricated bearings were also made. The upgraded configuration, known as Vapor Compression Distillation Subsystem, Enhanced Advanced Preprototype Configuration (VCD2B), tripled the water production rate with a corresponding lower specific energy.

Objective

The objective of this program was to continue the development of an advanced preprototype VCDS for the recovery of water from wastes aboard future spacecraft. The continued development included parametric testing and component evaluation program under contract Modification 10S, a component enhancement and testing effort identified under contract Modification 12S and the development of VCDS expert fault diagnostics routines containing expert knowledge of the VCD subsystem developers under contract Modification 13C.

The specific program objectives under Modification 10S included:

1. Broaden the parametric data base for future flight hardware optimization.

2. Upgrade VCDS centrifuge bearings (nonlubricated).

3. Reduce compressor speed to allow use of nonlubricated bearings.

4. Identify alternate peristaltic tubing material for the fluids pump.

5. Increase life and simplify design of magnetic drive.

6. Characterization testing of L/D = 1 Compressor and Fluids Pump.

7. Increased water production rate, i.e., lower specific energy.

The specific program objectives under Modification 12S included:

1. Develop improved key subsystem components emphasizing reliability, long life and maintainability features.

(a) Numbers in parentheses designate reference in Bibliography Section ( ).

2. Parametrically test the improved components integrated into the VCDS, with a 90-day mission simulation test as a goal.

3. Develop and test upgraded bearings for the centrifuge, compressor and idler pulley.

4. Develop and test an improved magnetic drive which eliminates life-limiting thrust bearings.

5. Integrate and test a L/D = 1 compressor within the VCD mechanical subsystem.

6. Develop and test an improved fluids pump harmonic drive externally retrofitted to the baseline fluids pump.

The specific program objectives under Modification 13C included:

1. To maximize VCDS operating time between shutdowns through the development of knowledge-based (expert) fault diagnostics, fault prevention and isolation.

2. Define and develop the fault diagnostics knowledge of the VCDS developers using monitoring and diagnostics principles based upon deductive reasoning and logic.

All objectives were accomplished during the course of the program.

End Products

The end products of the Modification 10S contractual effort were:

1. Scientific and engineering experimental data as needed to optimize the performance and process dynamics of the VCDS (VCD2A configuration).

2. A developed VCDS (VCD2A Configuration) that has undergone thorough developmental testing and calibration.

3. A Compressor Test Stand with new L/D = 1 Compressor (SN01 unit) delivered to NASA JSC.

4. A Fluids Pump Test Stand with a baseline Fluids Pump (SN02 unit) delivered to NASA JSC.

5. A range of technical documents to communicate program status and results besides the two design reports.

6. A Final Report summarizing the results of all added program work.

The end products for Modification 12S efforts were:

1. A second fluids pump harmonic drive package for external integration to the existing VCD2A fluids pump for development testing prior to delivery to NASA JSC.

2. A second L/D = 1 compressor (SN02 Unit), for VCDS integration and development testing prior to delivery to NASA JSC.

3. Upgraded centrifuge, compressor and idler pulley bearings fabricated and tested within the VCDS and delivered to NASA JSC.

4. Two improved magnetic coupling subassemblies (SN01 and SN02 units) for VCDS and compressor test stand evaluation, delivered to NASA JSC.

5. A developed VCDS, containing upgraded and improved subsystem components (VCD2B configuration) that has undergone thorough developmental testing and calibration.

The end products for Modification 13C efforts were:

1. Development of improved process operating controls to provide greater process reliability efficiency and maintainability utilizing the expert knowledge of the VCDS developers.

2. Final Report sections summarizing the results of Modification 13C efforts incorporated with modifications 10S and 12S results. Included were report sections defining the applicability of the generic portions of the improved process controls and monitoring to other Environmental Control and Life Support (ECLS) subsystems.

All end products were completed during the course of the program.

Program Organization

The program consisted of accomplishing 15 major tasks detailed in a Statement of Work (SOW). The tasks included the following:

1.0 VCDS Parametric Testing
2.0 VCDS Refurbishment
3.0 Test Stand Development (two test stands)
4.0 Waste Fluid Pretreatment Assessment
5.0 Data Management (Mod. 10S)
6.0 Program Management (Mod. 10S)
7.0 VCDS Refurbishment
8.0 VCD2A to VCD2B Conversion
9.0 Other Components Development
10.0 VCD2B Testing
11.0 Data Management (Mod. 12S)
12.0 Program Management (Mod. 12S)
13.0 Added/Deleted Tasks
14.0 Expert Fault Diagnostics Development
15.0 Program Management and Documentation (Mod. 13C)

The SOW was divided into many subtasks to clearly define the effort.

The program documentation included 75 technical reports. These documents included 28 monthly progress reports, the Final Report as well as all other technical reports.

Report Organization

The Final Report has been organized as a summary of the work completed for the program. It consists of two standalone documents. This document is Volume I. It consists of a summary of the total work effort except for the VCDS expert fault diagnostics development (Volume II).

For this document, the advanced preprototype VCDS parametric testing including system description, test facilities, parametric testing results and optimum operating conditions are presented first. The VCDS post-test refurbishment is then discussed followed by the test stand design and development. Related advanced technology efforts are then discussed followed by conclusions made from the activities and recommendations for future efforts.

ADVANCED PREPROTOTYPE PARAMETRIC TESTING

The following section includes a system and Test Support Accessories (TSA) description, the VCD2A and VCD2B configuration testing and parametric test results as well as the VCD2A and VCD2B optimum operating conditions and characteristics.

System Description

The advanced preprototype VCDS, designated as the VCD2A, was designed to recover over 95% of the water contained within projected Space Station wastewaters. The subsystem design process capacity was retained at an approximate six-person crew level (i.e., 32.7 kg/day (72 lb/day)) based upon urine and hygiene wastewater to permit maximum benefit from previous VCDS hardware development. However, the actual capacity demonstrated has been tripled (98.2 kg/day (216 lb/day)) with the now existing VCD2B configuration.

The VCD process recovers the latent heat of condensation by compressing the water vapor in order to raise its saturation temperature, and then condensing it on a surface which is in thermal contact with the evaporator (see Figure 1). The resulting heat flux from the condenser to the evaporator evaporates an equal mass of water from the wastewater. The only additional energy required by the process is that necessary to compress the water vapor and overcome the process thermal and mechanical inefficiencies. The resultant VCD process, is, therefore, characterized by low specific energy for the water recovered from liquid wastes. Figure 2 is a functional schematic of the VCDS Distillation Unit.

Figure 3 is a mechanical schematic of the VCDS (both for VCD2A and VCD2B). Figure 4 shows the VCD2A mechanical package with the major components identified. The VCDS consists of only three primary components:

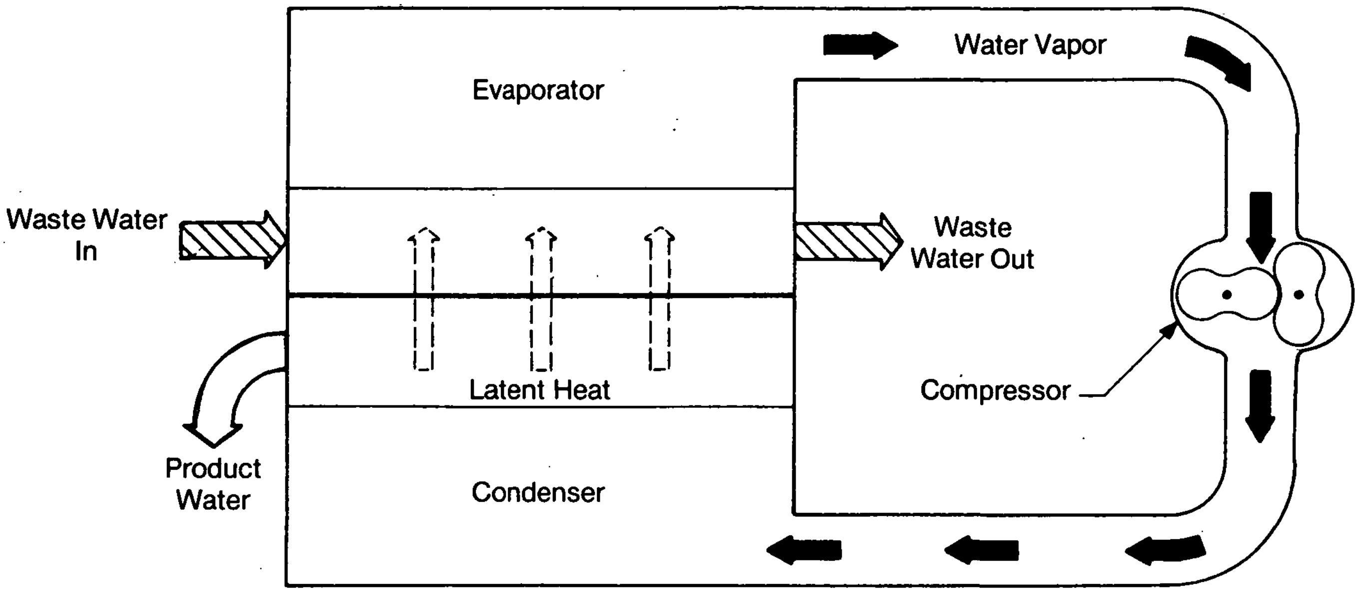

FIGURE 1 VAPOR COMPRESSION DISTILLATION CONCEPT

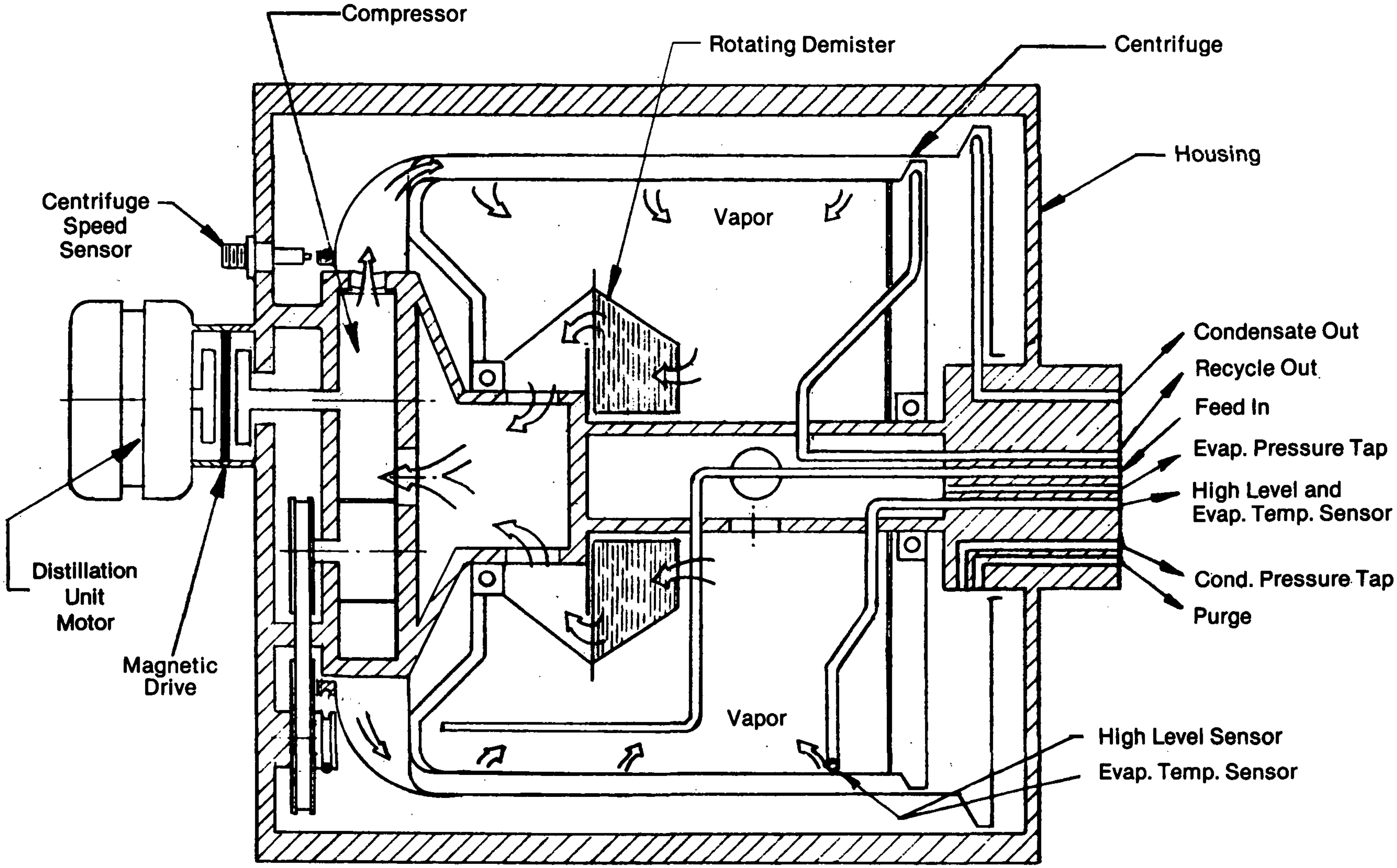

FIGURE 2 VCDS DISTILLATION UNIT FUNCTIONAL SCHEMATIC

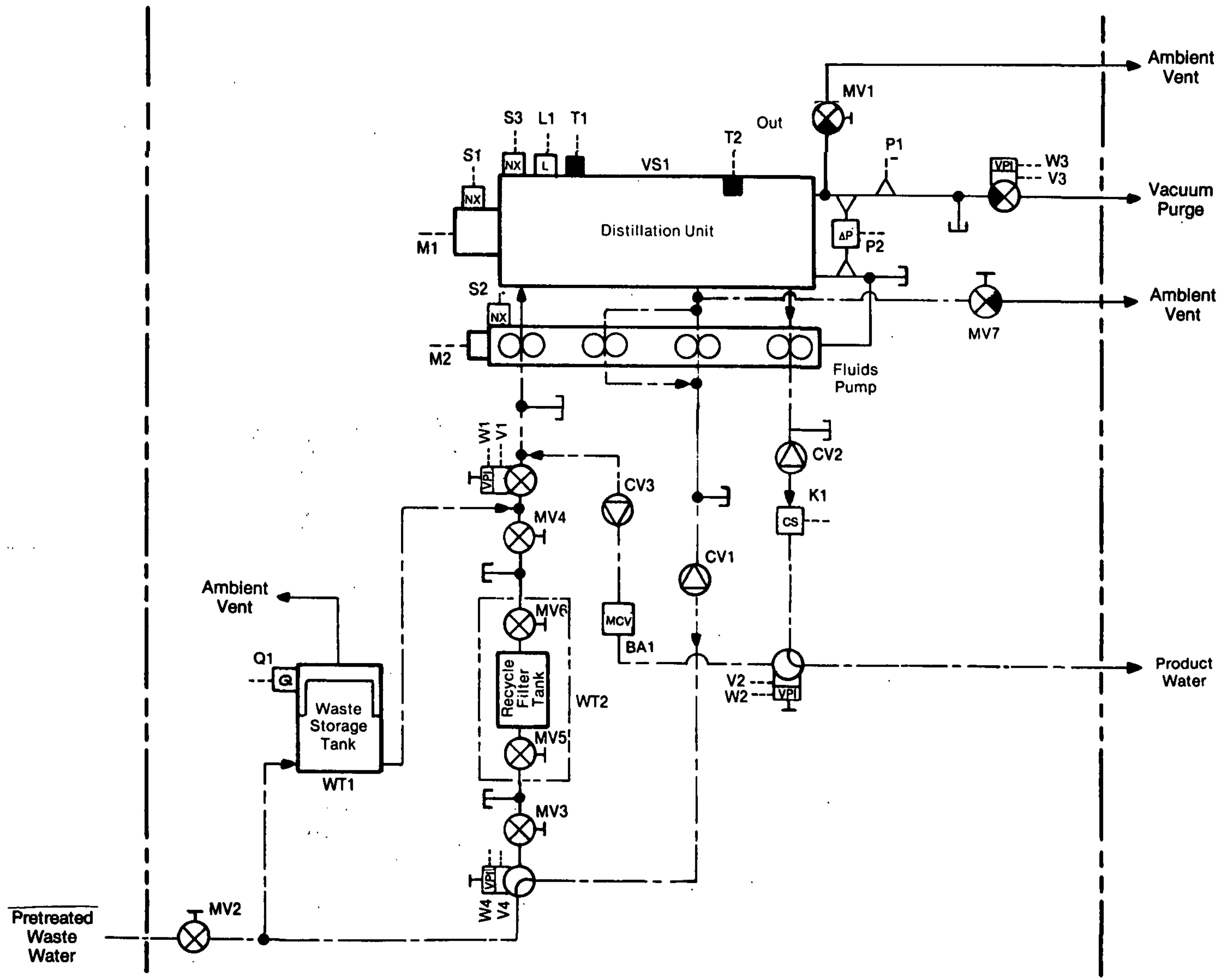

FIGURE 3 ADVANCED PREPROTOTYPE VCDS MECHANICAL SCHEMATIC WITH SENSORS

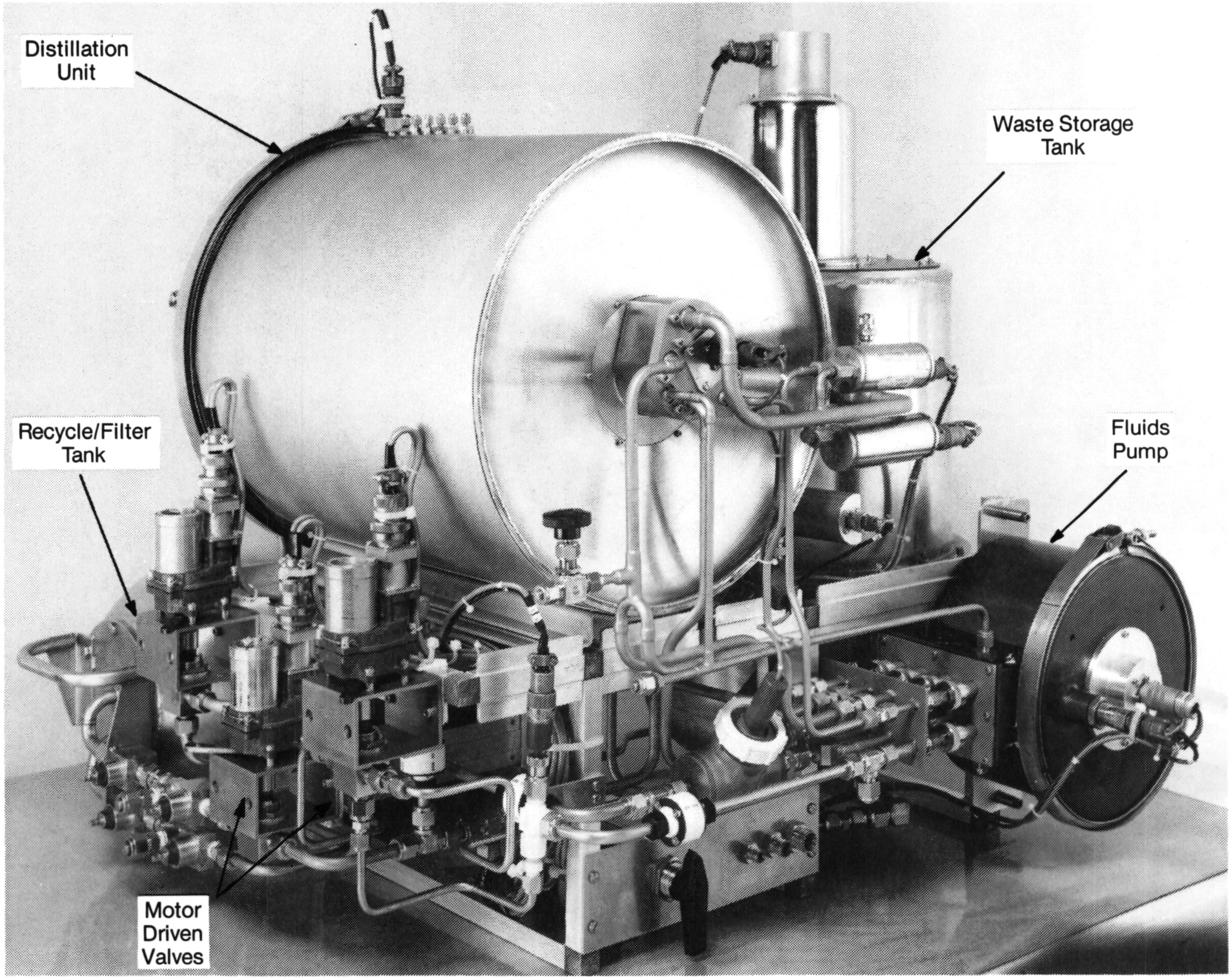

FIGURE 4 ADVANCED PREPROTOTYPE VCDS MECHANICAL PACKAGE

- Distillation Unit
- Fluids Pump
- Recycle/Filter Tank

Ancillary motor-driven valves and in-line sensors provide for process control and monitoring. A waste storage tank was packaged within the VCDS mechanical assembly for ease of development testing only. This storage tank will ultimately be located within a Space Station Waste Collection Subsystem, which will then supply the pretreated wastewater to a VCDS for water recovery.

The distillation unit is a highly integrated component where phase change water recovery and waste fluids management occur. The fluids pump (M2) discharges wastes to the inner surface of the evaporator drum within the distillation unit (VS1) at a rate greater than the water recovery rate. The excess wastewater feed is returned through a recycle/filter tank (WT2) by the fluids pump. The recirculation pumpout has twice the capacity of the wastewater feed input to prevent liquid buildup in the distillation unit.

The condenser/evaporator drum is rotated by a brushless DC motor (M1) via a hermetically sealed magnetic coupling to maintain the evaporator fluid liquid/vapor interface in zero gravity. Vapors produced in the evaporator are compressed by a rotary lobe compressor, raising the condensation temperature and pressure of the vapor. The compressed vapors are directed against the outer diameter of the evaporator drum, where they give up their latent heat and condense. The latent heat of condensation is then transferred through the very thin 0.089 cm (0.035 in) metallic wall of the evaporator drum, providing the required latent heat of evaporation.

Condensate is pumped from the distillation unit by the fourth section of the fluids pump past a conductivity (K1) sensor. This sensor provides initial product water quality monitoring and controls a diverter (V2) if water quality is measured as unsatisfactory. Unsatisfactory water is automatically rejected and reprocessed. Only low conductivity (less than 50 micromhos/cm) product water is delivered to post-treatment and water storage. A microbial check valve (BA1) acts to prevent back-contamination of the product water in the reprocessing loop. Concentrated solids from the wastewater are collected within the recycle/filter tank for removal and disposal on a 90-day maintenance cycle.

Collection and initial pumpout of the product water and recirculating wastewater are accomplished via stationary impact tubes. A relative velocity is imparted to the liquids by the condenser/evaporator drum which rotates at a very low speed (28.2 rad/sec (270 rpm)).

Test Facilities and Hardware

The following section includes a discussion on the necessary VCDS TSA, other accessories and test hardware used for the program.

Test Support Accessories

The baseline TSA required for both the VCD2A and VCD2B testing are shown in Figure 5. They consist of:

1. Spacecraft power and central instrumentation simulator--The TSA spacecraft power and control information simulator converts three phase, 220 V, 60 cycle AC power into 115/200 V, 400 cycle, 1- and 3-phase AC power and supplied regulated 28±4 VDC power.

2. Water Sources Supply--The TSA water source supply provides pretreated urine, urinal flush water and distilled water to the subsystem.

3. Fluids Supply Unit--The TSA fluids supply unit provides a vacuum source to the subsystem.

4. Instrumentation--The TSA instrumentation displays subsystem parameters during operation, collects and stores monitored parameters and displays stored data. Table 1 describes the instrumentation used to monitor the subsystem parameters.

5. Expendables Supply--The TSA expendables supply provides the necessary pretreat chemicals.

6. Product Water Collection/Analysis--The TSA product water collection is provided to accumulate the product water so that production could be determined and analysis performed.

Other Accessories

In addition, the following accessories were incorporated for both the VCD2A and VCD2B:

1. The Distillation Unit Window Kit--The distillation unit window allows direct observation of the evaporator during operation. Figure 6 shows the window kit parts and matching metallic blank-off conversion parts if windows removal is desired. Testing has indicated that the windows do not affect VCDS performance.

   The opportunity to observe the evaporator side of the VCDS Distillation Unit during operation by way of the distillation unit window kit was made available on two occasions during the course of the VCDS Technology Review Meetings. The first observation session was held on March 21, 1985 and was made with the VCDS in operation using water as the wastewater feed source. The second observation session was held on March 22, 1985 and was conducted with pretreated urine. The following observations were made by NASA's and Life Systems' personnel during viewing through the VCDS windows.

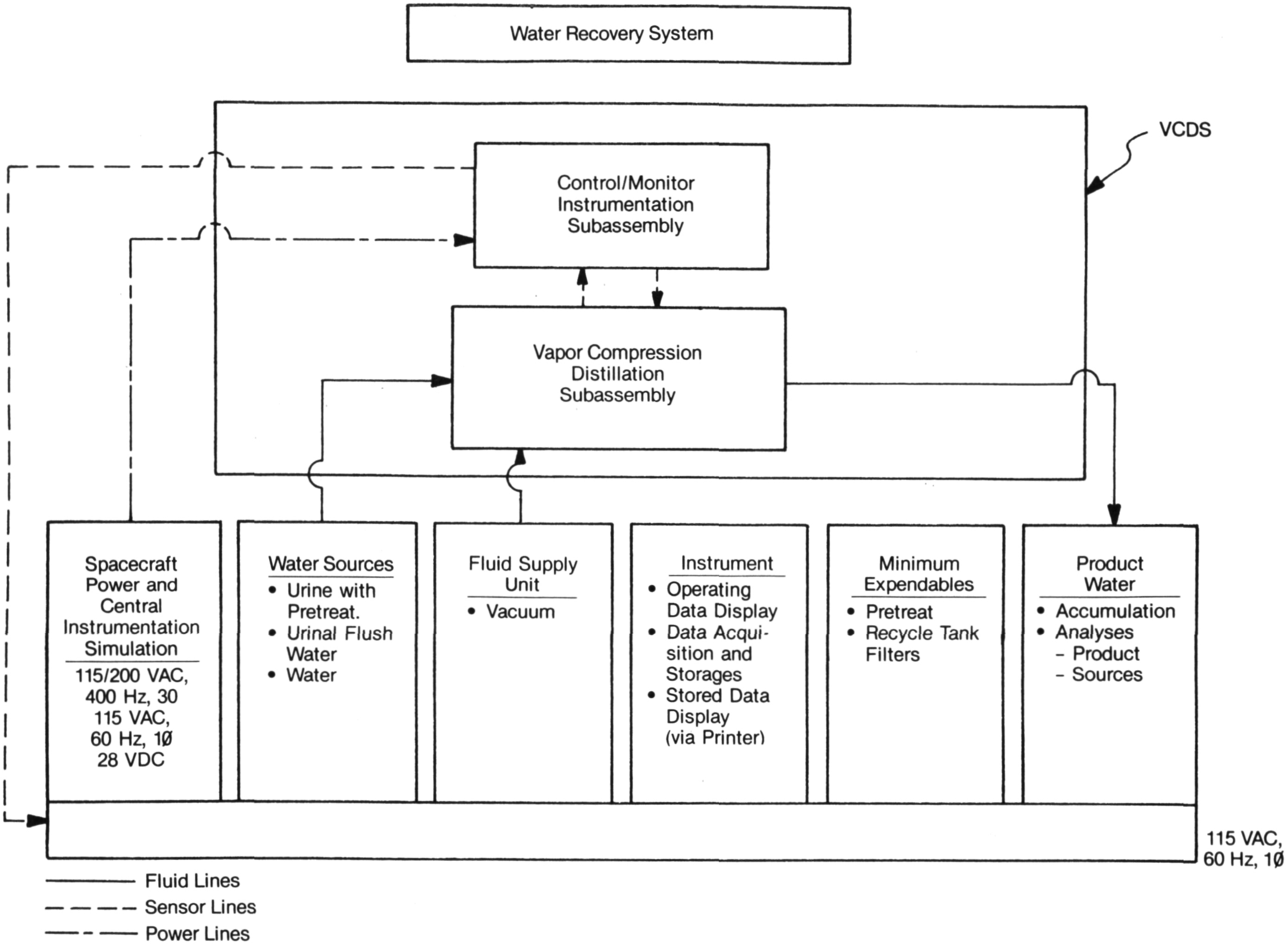

FIGURE 5 VCDS/TSA INTERFACES

TABLE 1 VCDS PARAMETRIC TEST INSTRUMENTATION

Type of Measurement	Type of Instrument	Measurement Location	Sensor Symbol	Expected Accuracy
Temperature	Thermistor	Condenser	T1	±1% (3 F)
	Thermistor	Evaporator	T2	
	Thermometer[a]	Ambient	ET1	
	Thermometer[a]	Hot Box	ET2	
	Thermometer[a]	Product Water	ET3	
	Thermocouple	Harmonic Drive	ET4	
Pressure and Pressure Differentials	Transducer	Condenser	P1	±2%
	Transducer	Compressor Delta P	P2	
	Gauge[a]	Evaporator	EP1	±2%
	Gauge[a]	Pump Casing	EP3	
	Gauge[a]	Harmonic Drive	EP4	
Speed, Rotational	Magnetic Pickup	Still Motor	S1	±3%
	Magnetic Pickup	Fluids Pump	ES2[b]	
	Magnetic Pickup	Centrifuge	S3	
Power[a]	Ammeter	Still Motor	N/A	±1/2%
Liquid Quantity	Magnet/Reed Switches	Waste Storage Tank	Q1	±3%
Liquid Level	Conductivity	Evaporator	L1	N/A
Conductivity	Conductivity Sensor	Condensate	K1	±3%
Water Quality[a]				
pH	pH Meter	Analytical Lab	N/A	±1%
Conductivity	Conductivity Bridge	Analytical Lab	N/A	±3%
Total Carbon	TOC Analyzer	Analytical Lab	N/A	±1 ppm or ±3%
Inorganic Carbon	TOC Analyzer	Analytical Lab	N/A	±1 ppm or ±3%
Ammonia	Titration	Analytical Lab	N/A	--
Urea	Electrophotometer	Analytical Lab	N/A	±1%
Product Water Rate[b]	Volumetric Flask	Analytical Lab	N/A	±0.3%
	Stop Watch	Analytical Lab	N/A	±0.1 sec
Recycle Loop Solids	Lab Balance[c]	Analytical Lab	N/A	±10%
	Refractometer	VCDS Test Area	N/A	±10%

(a) With Life Systems' Laboratory/TSA facilities.
(b) Manual measurement using stopwatch.
(c) Recycle brine sample baked, solids residue weighed.

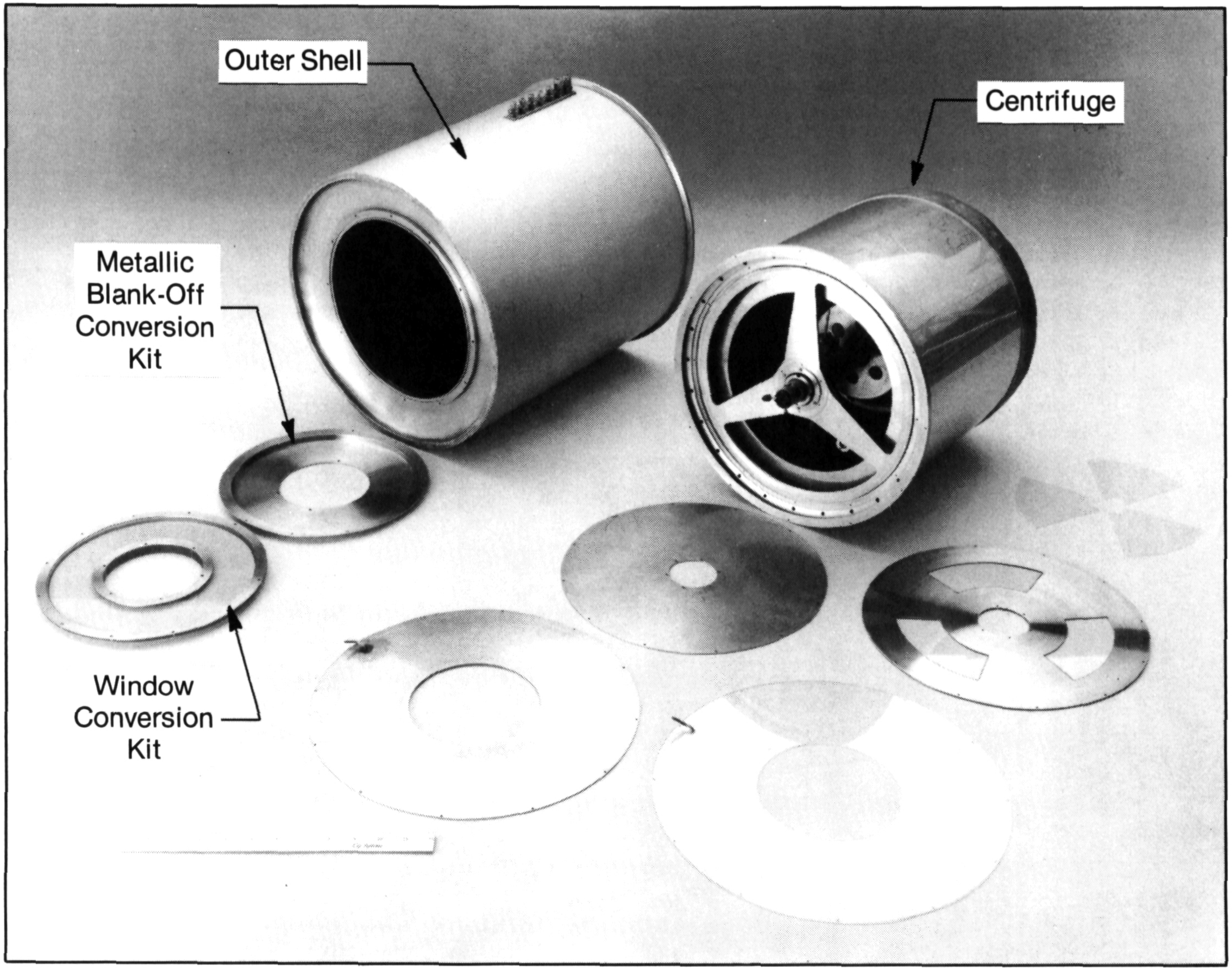

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FIGURE 6 VCD2A DISTILLATION UNIT WINDOWS

a. The general appearance of the evaporator fluid film during operation with water was one in which the film appeared as if it were a glassy or glossy surface finish on the evaporator surface with no signs of rippling or fluid flow. It should be noted, that during previous VCDS shakedown testing in 1983, it was calculated that the residence time for the fluid within the evaporator was on the order of 2.8 minutes. This means that the fluid velocity across the evaporator surface would be very slow and would more than likely appear as a static shiny surface effect on the evaporator.

b. Fluid discharging from the waste feed discharge tube onto the back surface of the centrifuge showed a pulsating flow as would be expected with a peristaltic fluids pump.

c. At initial startup with a vacuum-dried centrifuge, it was noted that the wastewater discharging from the waste feed tube would be carried in a stream like fashion away from the discharge tube with centrifuge rotation until total film coverage occurred on the centrifuge back surface and the evaporator surface. After film formation had occurred, no sign of fluid streaking or movement was visible, indicating that the back surface of the centrifuge was probably completely covered with a liquid film which was moving out evenly across the cylindrical portion of the evaporator surface.

d. It was noted that the presence of the pick-up tubes within the pick-up tube grooves of the centrifuge caused a visible splashing action as the fluid would impact into the tube to be pumped out of the centrifuge. Visible signs of this were droplets of water clinging to the various clear plastic separator plates as one would view the centrifuge during operation.

e. As expected, there was no visual indication of water vapor or fog within the volume of the evaporator cavity in the centrifuge.

f. During operation with pretreated urine wastewater feed, it was noted that the same waste feed discharge fluid flow effect takes place with urine as with water as the working fluid.

g. Since the pretreated urine has a slightly darker color than plain water, the appearance of the film on the evaporator surface was more pronounced (darker in color) due to this color difference.

h. The evaporator film surface during operation with pretreated urine appeared to be very active in that small wakes and surface bubbling were observed. It was speculated that the surface bubbling effect was due to off-gasing of volatile components from the urine within the subatmospheric environment of the distillation unit evaporator.

2. Recycle Filter Tank--A small (1 liter) and large (20 liter) plastic recycle/filter tank, each utilizing a clear plastic tank body was used for the VCD2A and VCD2B parametric testing (see Figure 7). A small commercial liquid filter was used in both the recycle/filter tanks. The clear tank body permitted viewing of the filter elements and concentrating recycle fluid during VCDS operation.

   In comparison, the one-liter tank permitted accelerated recycle loop solids accumulation over the larger replacement recycle/filter tank. Based on test experience, the small tank reached 50% solids level within 35 hours of VCDS baseline operation compared to approximately 700 hours for the large tanks. The small recycle/filter tank was found to be very instrumental during the parametric tests where quick solids buildup was desirable. Where long-term VCDS operation was required, i.e., between mini-parametric tests, the large recycle/filter tank was employed.

Test Hardware

The test hardware for the VCDS parametric test programs consisted of the following major components:

1. Model 140A Control/Monitor Instrumentation (C/M I).
2. Advanced preprototype VCDS mechanical subsystem.

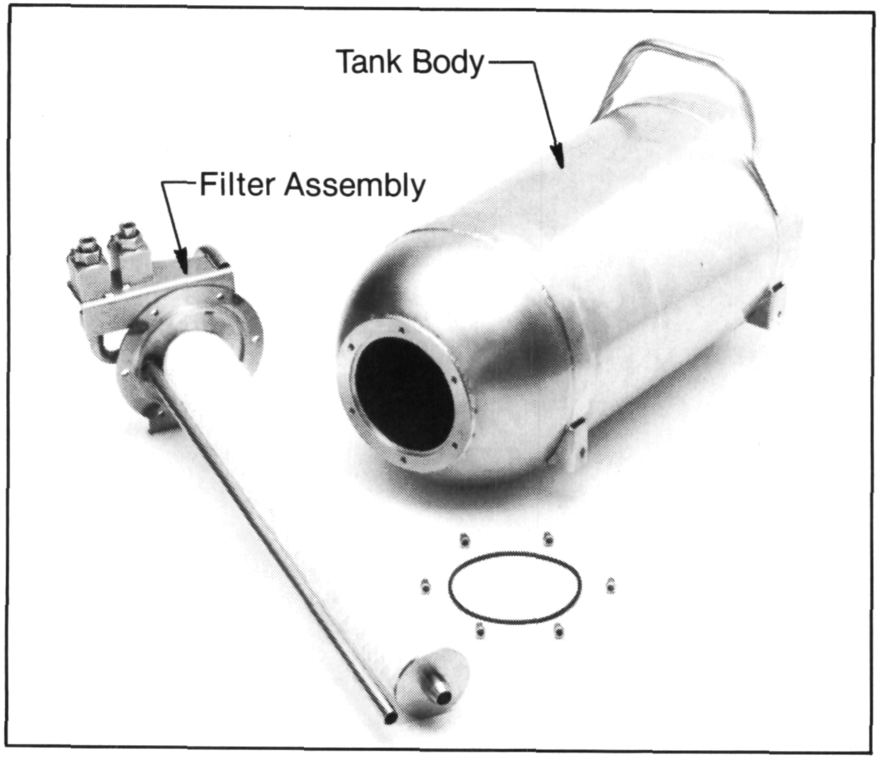
Figure 8 presents the advanced preprototype VCDS mechanical subsystem package and the Model 140A C/M I. Figure 9 presents the VCDS interface block diagram.

Testing of VCD2A Configuration

The purpose of the VCD2A parametric test program was to establish a data base which could be used to define optimum operating characteristics for future VCDS prototype (i.e., VCD2B) and flight hardware. Key process parameters such as water production rate, water quality and specific energy were defined as a function of condenser temperature, recycle loop dissolved solids and fluids pump speed. The latter operating parameter (fluids pump speed) governs the flow rates of waste feed and waste recirculation to and from the distillation unit.

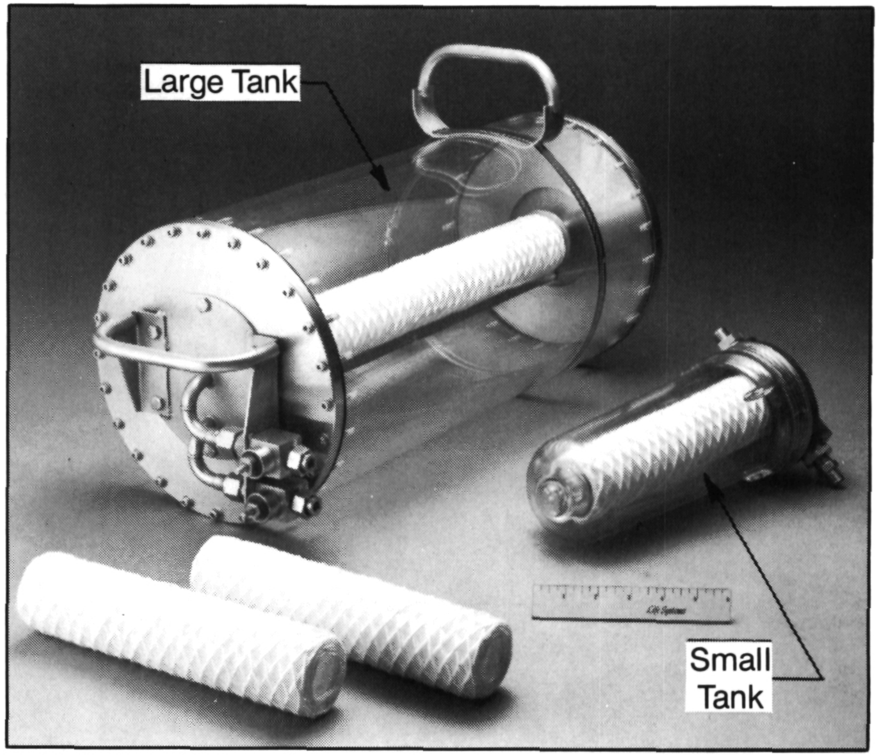
The VCD2A parametric test program was conducted to define VCDS performance as a function of:

Baseline Design



- 20 Liter Fluid Capacity
- From SSP Program (1970's)
- Stainless Steel Construction

Parameteric Test (Experimental) Designs



- 20 Liter Fluid Capacity (Large)
- Baseline Filter Assembly Retrofitted into Clear Plastic Tank Body (Large)
- 1 Liter Fluid Capacity (Small)

FIGURE 7 VCD2A RECYCLE/FILTER TANKS

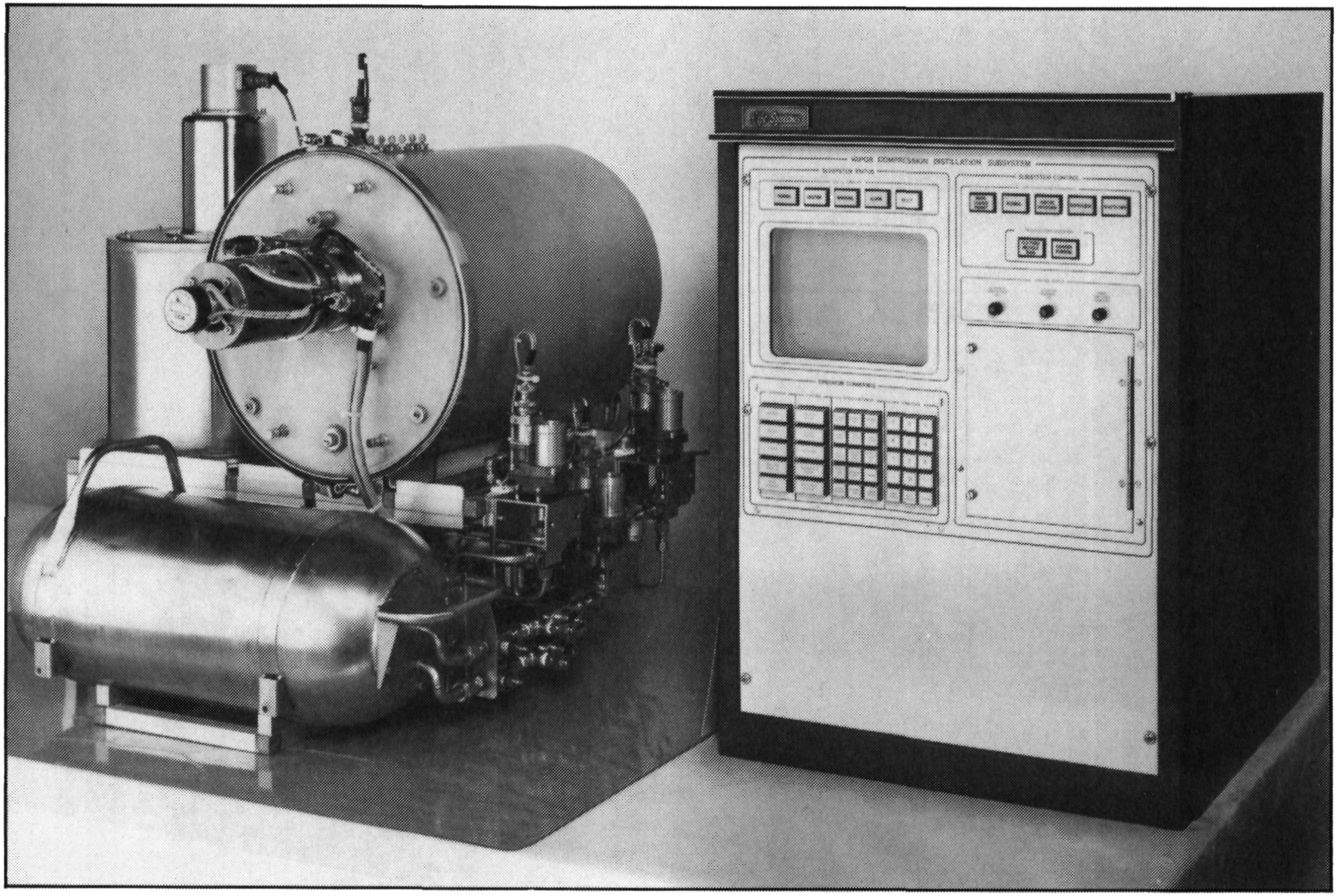


FIGURE 8 VCDS MECHANICAL PACKAGE AND C/M I

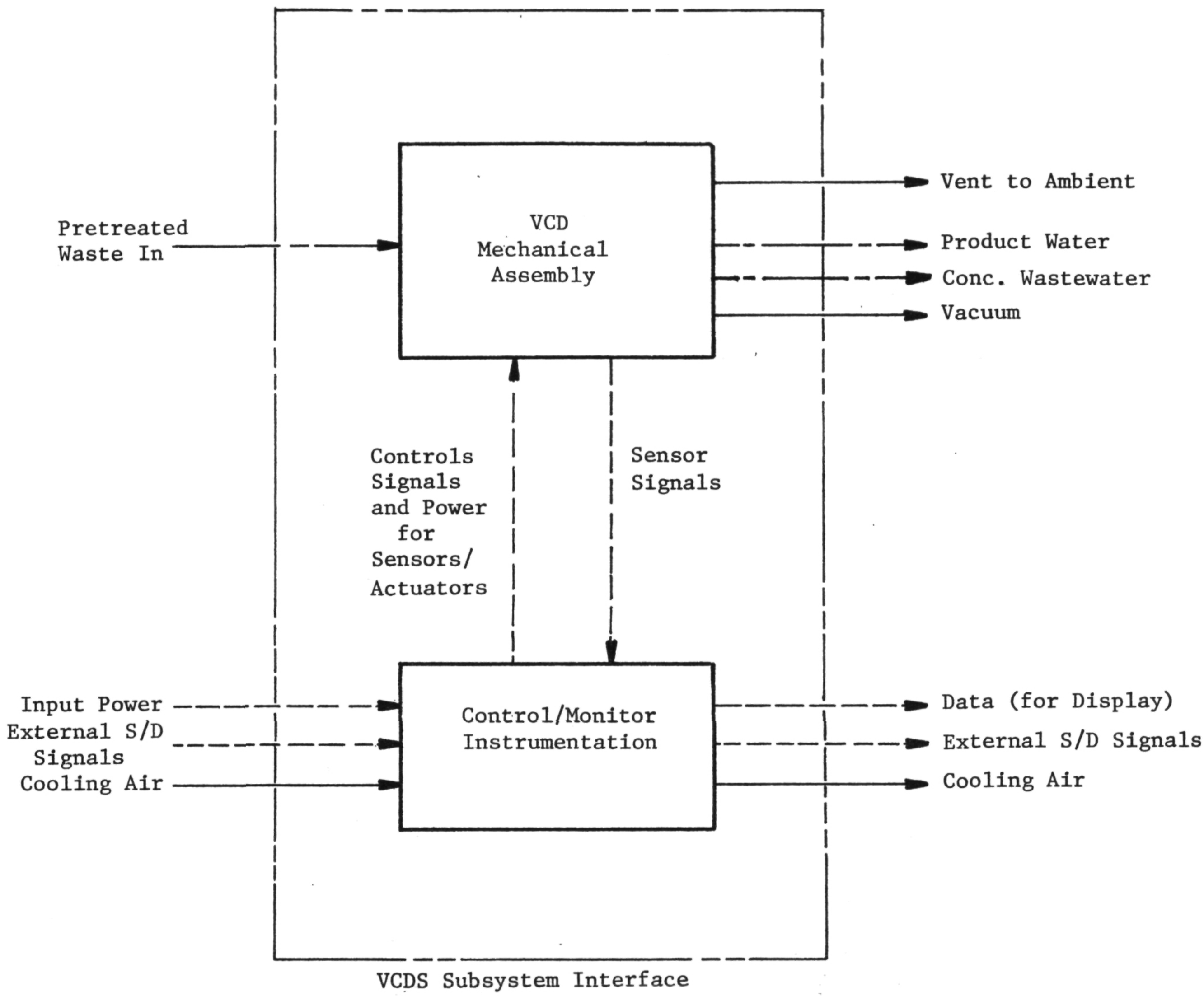


FIGURE 9 VCDS PROCESS INTERFACES BLOCK DIAGRAM

- Condenser temperature range of 305 to 338 K (90 to 150 F).

- Dissolved solids concentration range of 0 to 30%.

- Wastewater recirculation flow rate range of 1.8 to 15.9 kg/h (4 to 35 lb/hr) (a direct function of fluids pump speeds ranging from 0.10 to 2.1 rad/sec (1 to 20 rpm)).

Testing was divided into three phases:

- Twenty 0% Solids Characterization Tests at five different fluids pump speeds, while operating at each of four constant condenser temperatures.

- Eight Solids Scan Tests at two fluids pump speeds while operating at four constant condenser temperatures. The wastewater solids concentration was allowed to increase from 2.3% (fresh pretreated urine and flushwater) to 30% (wastewater concentrate).

- Three Constant Solids Tests at 0, 15 and 30% solids levels, respectively, for five fluids pump speeds at a given condenser temperature.

The VCD2A parametric test program tasks are presented in Table 2.

Testing of VCD2B Configuration

The VCD2B parametric testing was done in similar fashion to the VCD2A parametric testing. Hence, the parametric test results for both configurations will be presented in unison. While the relative relationships between key parameters were similar for both configurations, the water production rate, however, of the VCD2B had tripled over that of the VCD2A.

The VCD2B parametric test program tasks are presented in Table 3.

Parametric Test Results

The VCD2A and VCD2B test programs were successfully completed during 1985 and 1986, respectively. Since key operating parameters were similar for both configurations, the parametric test results will be presented in unison. The test results are summarized as follows:

1. Water Quality versus Condenser Temperature (see Figure 10)--Analysis of VCD2A and VCD2B test data for water quality indicated that as condenser temperature increases (90 to 150 F):

    - pH decreases with a lower limit not exceeding 3.0
    - Ammonia increased with an upper limit not exceeding 1.0 ppm
    - Conductivity remains constant within a 60 ±30 mmho/cm band

TABLE 2 VCD2A PARAMETRIC TEST PROGRAM[a]

Test No.	Test Name	Test Time, Hr Duration	Accum.	Test Variables Fluids Pump Speed, RPM	Recycle Solids %	Condenser Temperature F	Waste Fluid	Process Configuration[b]
1[c]	15.2 RPM/0% Solids/90 F	2	2	15.2	0[d]	90	Distilled Water	Rec/Filter
2	13.0 RPM/0% Solids/90 F	2	4	13.0	0	90	Distilled Water	Rec/Filter
3	11.0 RPM/0% Solids/90 F	2	6	11.0	0	90	Distilled Water	Rec/Filter
4	8.6 RPM/0% Solids/90 F	2	8	8.6	0	90	Distilled Water	Rec/Filter
5	6.5 RPM/0% Solids/90 F	2	10	6.5	0	90	Distilled Water	Rec/Filter
6	15.2 RPM/0% Solids/110 F	2	12	15.2	0	110	Distilled Water	Rec/Filter
7	13.0 RPM/0% Solids/110 F	2	14	13.0	0	110	Distilled Water	Rec/Filter
8	11.0 RPM/0% Solids/110 F	2	16	11.0	0	110	Distilled Water	Rec/Filter
9	8.6 RPM/0% Solids/110 F	2	18	8.6	0	110	Distilled Water	Rec/Filter
10	6.5 RPM/0% Solids/110 F	2	20	6.5	0	110	Distilled Water	Rec/Filter
11	15.2 RPM/0% Solids/125 F	2	22	15.2	0	125	Distilled Water	Rec/Filter
12	13.0 RPM/0% Solids/125 F	2	24	13.0	0	125	Distilled Water	Rec/Filter
13	11.0 RPM/0% Solids/125 F	2	26	11.0	0	125	Distilled Water	Rec/Filter
14	8.6 RPM/0% Solids/125 F	2	28	8.6	0	125	Distilled Water	Rec/Filter
15	6.5 RPM/0% Solids/125 F	2	30	6.5	0	125	Distilled Water	Rec/Filter

continued-

(a) Task 1.8, Life Systems' Program Plan TR-471-22A.
(b) Recycle fluid flow through Waste Storage Tank (WT1) or Recycle/Filter Tank (WT2).
(c) Change to fresh 1 L capacity commercial Recycle/Filter Tank initially filled with distilled water (0% solids), before starting test.
(d) Baseline VCDS operating parameter (VCD2A).

Table 2 - continued

		Test Time, Hr		Test Variables				
Test No.	Test Name	Duration	Accum.	Fluids Pump Speed, RPM	Recycle Solids %	Condenser Temperature F	Waste Fluid	Process Configuration
16	15.2 RPM/0% Solids/150 F	2	32	15.2	0	150	Distilled Water	Rec/Filter
17	13.0 RPM/0% Solids/150 F	2	34	13.0	0	150	Distilled Water	Rec/Filter
18	11.0 RPM/0% Solids/150 F	2	36	11.0	0	150	Distilled Water	Rec/Filter
19	8.6 RPM/0% Solids/150 F	2	38	8.6	0	150	Distilled Water	Rec/Filter
20	6.5 RPM/0% Solids/150 F	2	40	6.5	0	150	Distilled Water	Rec/Filter
21	Solids Scan 15.2/90	35[a]	74	15.2	(b)	90	Pretreated Urine	Rec/Filter[c]
22	Solids Scan 15.2/110	29	104	15.2	(b)	110	Pretreated Urine	Rec/Filter[c]
23	Solids Scan 15.2/125	25	129	15.2	(b)	125	Pretreated Urine	Rec/Filter[c]
24	Solids Scan 15.2/150	21	150	15.2	(b)	150	Pretreated Urine	Rec/Filter[c]
25	Solids Scan 3.5/90	35	185	3.5	(b)	90	Pretreated Urine	Rec/Filter[c]
26	Solids Scan 3.5/110	29	214	3.5	(b)	110	Pretreated Urine	Rec/Filter[c]
27	Solids Scan 3.5/125	25	239	3.5	(b)	125	Pretreated Urine	Rec/Filter[c]
28	Solids Scan 3.5/150	21	260	3.5	(b)	150	Pretreated Urine	Rec/Filter[c]
29	0% Solids Constant	16	276	(d)	0	110	Distilled Water	Rec/Filter
30	15% Solids Constant	16	292	(d)	15	110	(e)	Rec/Filter
31	30% Solids Constant	16	308	(d)	30	110	(f)	Rec/Filter

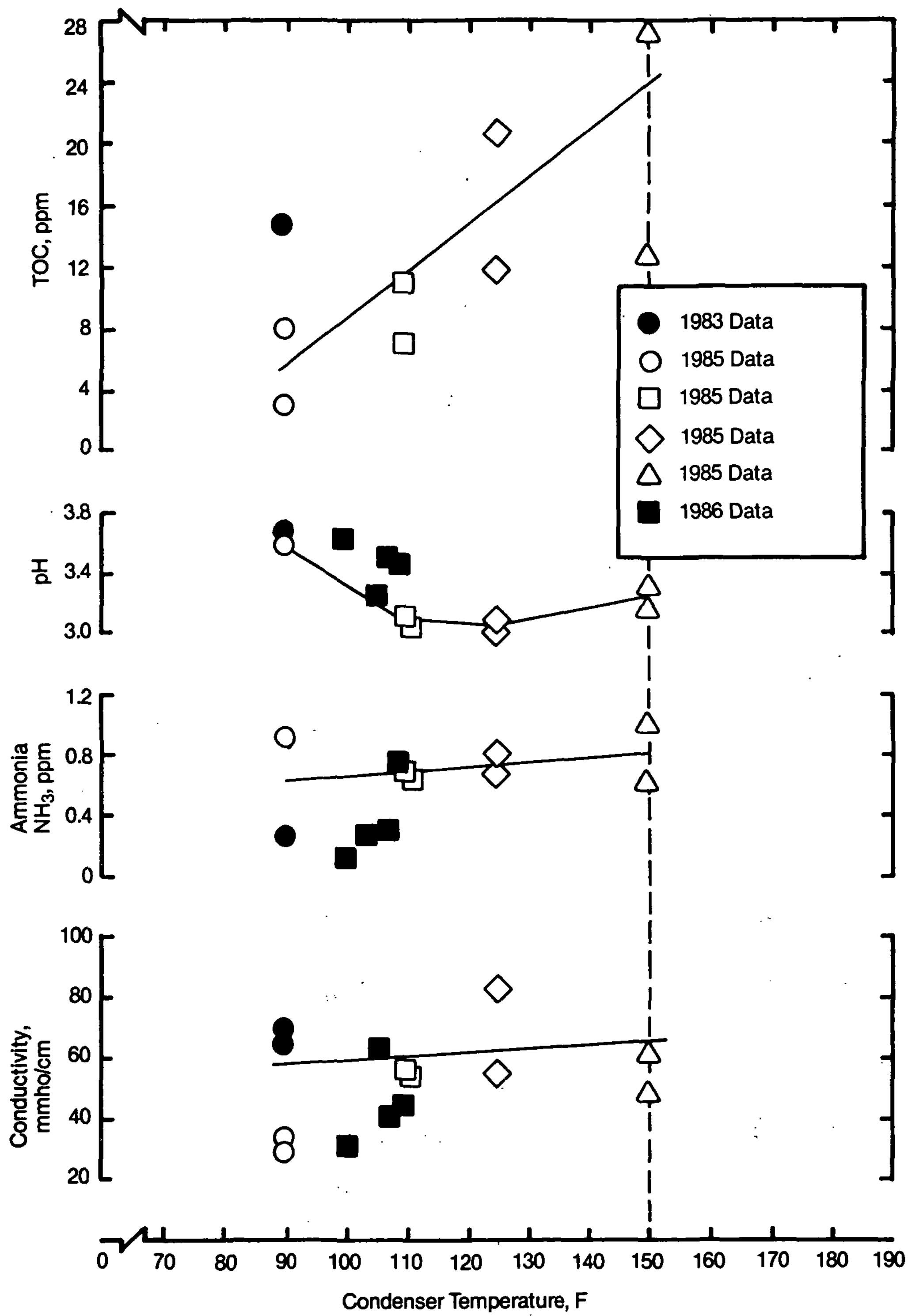
(a) Estimated test time, based upon previous testing experience.
(b) 2.3% initial solids level concentrating to a 30% solids level, prior to starting next test.
(c) Change to fresh 1 L capacity commercial Recycle/Filter Tank initially filled with 2.3% solids pretreated urine, before starting each test.
(d) Variable between 1.0 to 20 RPM during testing.
(e) Pretreated urine initially concentrated to 15% solids in the recycle loop, then maintained using distilled water.
(f) Pretreated urine initially concentrated to 30% solids in the recycle loop, then maintained using distilled water.

TABLE 3 VCD2B MINI-PARAMETRIC/MISSION SIMULATION TEST PROGRAM

Test No.[a,b]	Test Name	Test Time, hr Duration	Accum.	Test Variables: Pump Speed, rpm 5.0	8.5	11.0	15.2	Pump Testing Old	New	Compressor Speed, rpm 1,600	3,200	Condenser Temp., F	Recycle Solids, %	Waste Fluid	Recycle Tank
1	Compr. Eval. (3,200/90)	64	64	X	X	X	X	X	-	-	X	90	0	Water	Large
2	Compr. Eval. (3,200/110)	64	128	X	X	X	X	X	-	-	X	110	0	Water	Large
C1[a]	Distl. Unit Change	-	-	-	-	-	-	X	-	-	X	-	-	-	-
3	Compr. Eval. (1,600/90)	64	192	X	X	X	X	X	-	X	-	90	0	Water	Large
4	Compr. Eval. (1,600/110)	64	256	X	X	X	X	X	-	X	-	110	0	Water	Large
C2	Fluids Pump Change	-	-	-	-	-	-	-	X	-	X	-	-	-	-
5	Tubing Eval. (New/90)	64	320	X	X	X	X	-	X	-	X	90	0	Water	Large
6	Tubing Eval. (New/110)	64	384	X	X	X	X	-	X	-	X	110	0	Water	Large
7A	Const. Solids (15%)	64	448	X	-	-	-	-	X	-	X	110	15	Urine	Small
7B	Const. Solids (30%)	64	512	X	-	-	-	-	X	-	X	110	30	Urine	Small
8	Mission Simulation[c]	1,288	1,800	X	-	-	-	-	X	-	X	110	0 to 30	Urine	Large
9	Tubing Eval. (New/90)[d]	64	1,864	X	X	X	X	-	X	-	X	90	0	Water	Large
10	Tubing Eval. (New/110)[d]	64	1,928	X	X	X	X	-	X	-	X	110	0	Water	Large
15	Washwater	232	2,160	X	X	X	X	-	X	-	X	110	0 to 30	Wash-water	Small
C6	Disassembly/Inspection	-	-	-	-	-	-	-	X	X	-	-	-	-	-
Total			2,160												

(a) Actually "C" for configuration change as follows:
- C1 = change from 3,200 rpm to 1,600 rpm compressor drive.
- C2 = change from old to new pump tubes (interchange SN01 and SN02 fluids pumps).
- C6 = end of test program: subsystem disassembly and inspection.

(b) Actual test sequence was as follows: 1, 2, 5, 6, 8, 9, 10, 7A, 7B, 15, 3 and 4.
(c) 1,272 hr test to accumulate 90 days operation when added to other tests.
(d) Re-evaluation of "new" tubes after 1,500 hr operation.



(a) • Product Water from Urine Without Post-Treat

FIGURE 10 VCDS WATER QUALITY PARAMETERS VERSUS CONDENSER TEMPERATURE (1983, 1985 AND 1986 DATA)[(a)]

Table 4 describes the VCD2A and VCD2B average product water quality comparison. Table 5 presents the VCD2A product water chemical analysis compared to the SD-W-002 (1970) standard.

2. Water Quality versus Time (At Constant Temperature - See Figure 11)--The effects of VCDS operating time upon water quality while maintaining constant temperature over time are:

- Product water quality parameters (conductivity, pH, ammonia) remain basically constant with time as dissolved recycle loop solids increase from 2.3 to 30%.

- Dissolved solids in the recycle loop increase slightly less than linearly with time at a given constant condenser temperature.

- The rate of dissolved solids accumulation (the slope of the percent solids versus the time curve) increases with higher condenser temperatures.

3. Water Production Rate versus Condenser Temperature--The effect of condenser temperature and recycle loop dissolved solids content upon the VCD2A and VCD2B water production rates are depicted in the operating map shown in Figure 12. The operating region and design point for the original VCD2 subsystem are shown for reference. The results show that:

- Water production rate increases slightly more than linearly with condenser temperature for a given recycle loop solids level over the temperature range tested.

- For a constant condenser temperature, the water production rate decreases as recycle loop solids increase due to a progressive decrease in water vapor pressure of the concentrating wastewater.

A second 0% solids operating curve describes the VCD2B water production rate. The VCD2B has successfully achieved an operating condition of 9.0 lb/hr at 95 F and 0% solids. This is a 300% increase in water production rate over the previous VCD2A configuration which utilized a smaller compressor. The new compressor provides a 230% increase in pumping capacity, weighs 6% less than the smaller VCD2A compressor and requires only a 7% volume increase of the distillation unit for packaging.

Parametric testing was also done using washwater, as indicated in Figure 13, there was no notable difference between water production rate performance data for water (0% solids) and washwater.

TABLE 4 VCDS AVERAGE PRODUCT WATER QUALITY COMPARISON

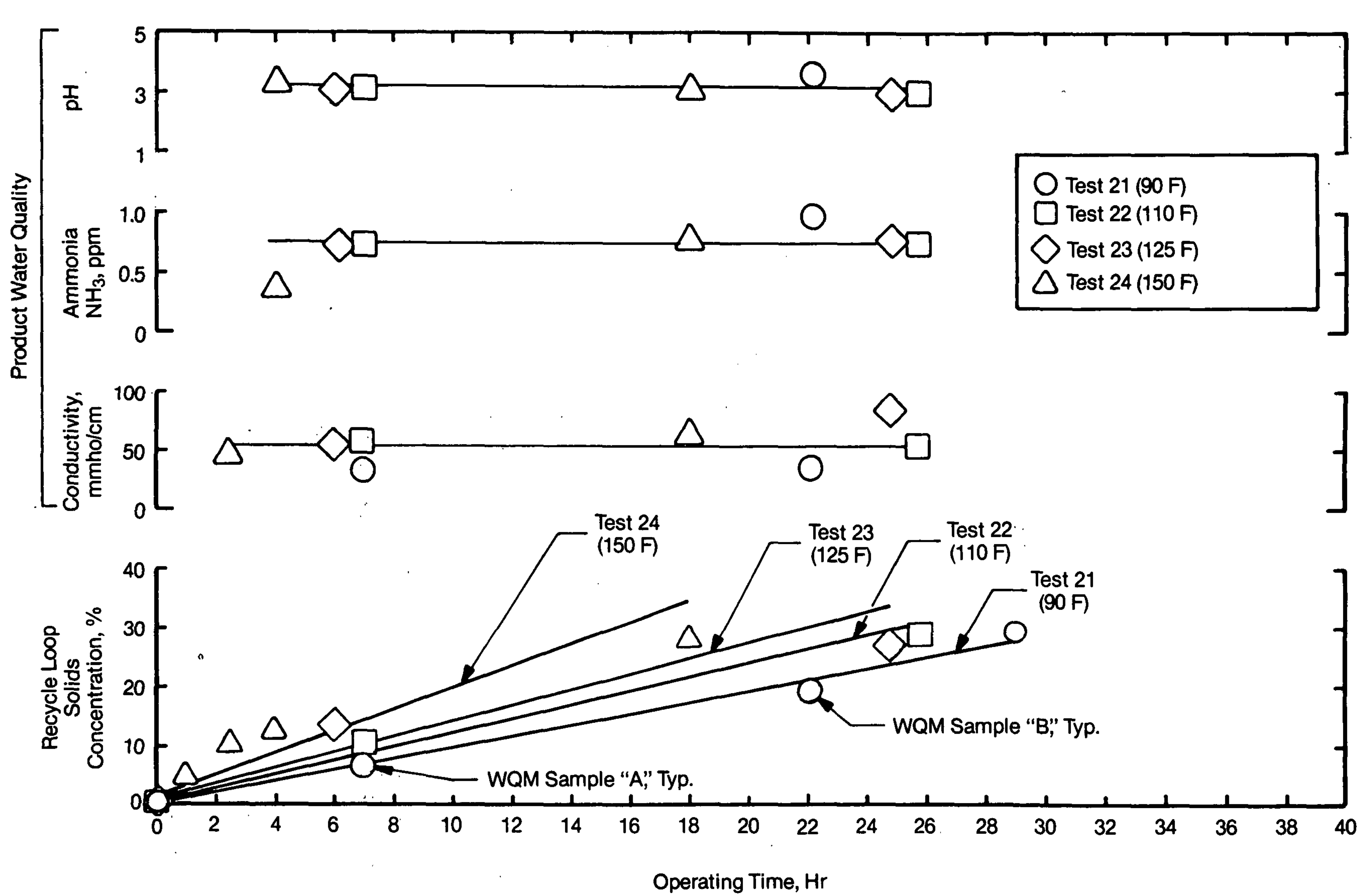
Test Data	Waste Feed	Post Treat	Condenser Temperature Range, F	Conductivity mmho/cm	pH	TOC, ppm	Ammonia, ppm
1983 Data[(a)]	Urine	No	90 to 95	63	3.7	15	0.27
1985 Data[(b)]	Urine	No	90 to 150	57	3.36	13	0.53
1985 Data[(c)]	Urine	No	150	69	3.29	20	0.66
1986 Data[(d)]	Urine	No	90 to 140	46	3.48	-	0.32
	Urine	Yes	90 to 140	81	7.14	-	0.02
	STS Wash	No	90 to 140	24	3.86	-	0.08
	Comm. Wash	No	90 to 140	8	5.31	-	-

(a) Advanced preprototype VCDS (VCD2A) development testing.
(b) VCD2A parametric test program
(c) Average water quality data at 150 F.
(d) VCD2B parametric test program.

TABLE 5 VCDS PRODUCT WATER CHEMICAL ANALYSIS[(a)]

Chemical Determination	Life Systems, Inc. and CSD Sample Numbers 21B 685-73	23A 785-92	25A 785-94	27A 885-31	SD-W-002 (1970) Standard
pH	4.2	3.7	3.8	3.8	6.0 to 8.0 at 77 F
Conductivity, μmho/cm	32.55	70.18	64.68	72.70	<0.33 at 77 F
Total Solids, ppm	4.9	2.8	2.4	4.1	2.0
Organic Carbon, ppm	8	12	10	18	1.0
Inorganic Carbon, ppm	<1	4	<1	1	-
Cadmium as Cd, ppb	<10	-	-	-	10
Chromium as Cr, ppb	<10	<10	<10	<10	50
Copper as Cu, ppb	<10	-	-	-	1,000
Iron as Fe, ppb	31	-	-	-	300
Lead as Pb, ppb	<10	-	-	-	50
Magnesium as Mg, ppb	25	<10	<10	-	-
Manganese as Mn, ppb	<10	<10	<10	-	50
Mercury as Hg, ppb	-	-	-	-	5.0
Nickel as Ni, ppb	<10	-	-	-	50
Potassium as K, ppb	540	15	55	-	-
Silver as Ag, ppb	<10	<10	<10	<10	50
Sodium as Na, ppb	420	14	22	-	-
Zinc as Zn, ppb	<10	15	35	-	5,000
Ammonia as N, ppb	995	162	122	660	-
Fluoride as F, ppb	-	-	-	-	-
Nitrate as N, ppb	-	-	-	-	-
Sulfate as SO_4^{2-}, ppb	-	-	-	-	-
Chloride as Cl^-, ppb	940	350	427	500	-
Urea, ppm	2.20	<0.5	<0.5	<0.5	-
Condenser Temperature, F	90	125	90	125	-

(a) VDC2A parametric test program.



(a) • VCD2A parametric test program
• Baseline fluids pump speed of 15.2 rpm
• Constant condenser temperature (T1) maintained per test

FIGURE 11 VCDS WATER QUALITY PARAMETERS VERSUS TIME[(a)]

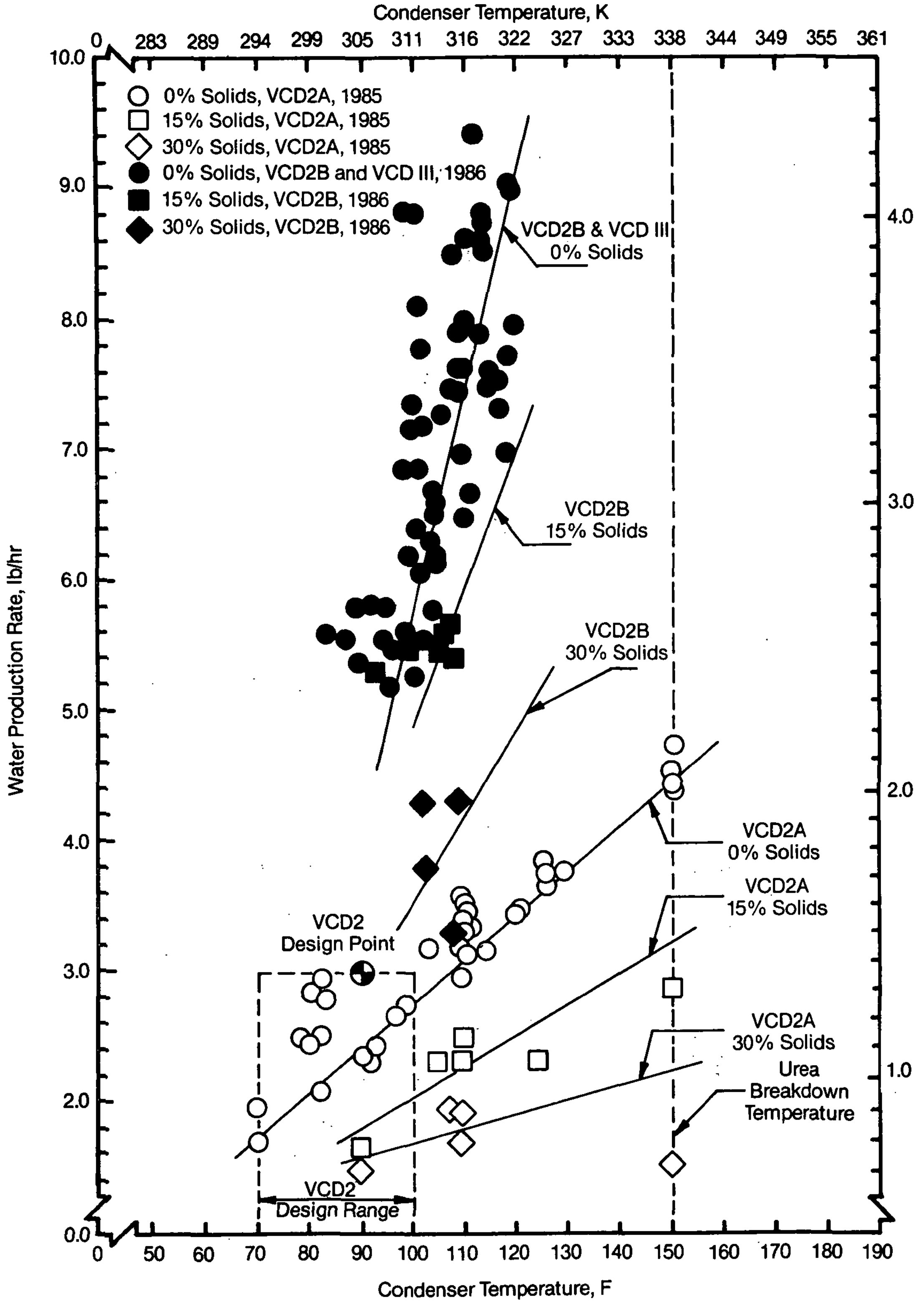


FIGURE 12 VCDS WATER PRODUCTION RATE VERSUS CONDENSER TEMPERATURE (1985 AND 1986 TEST RESULTS)

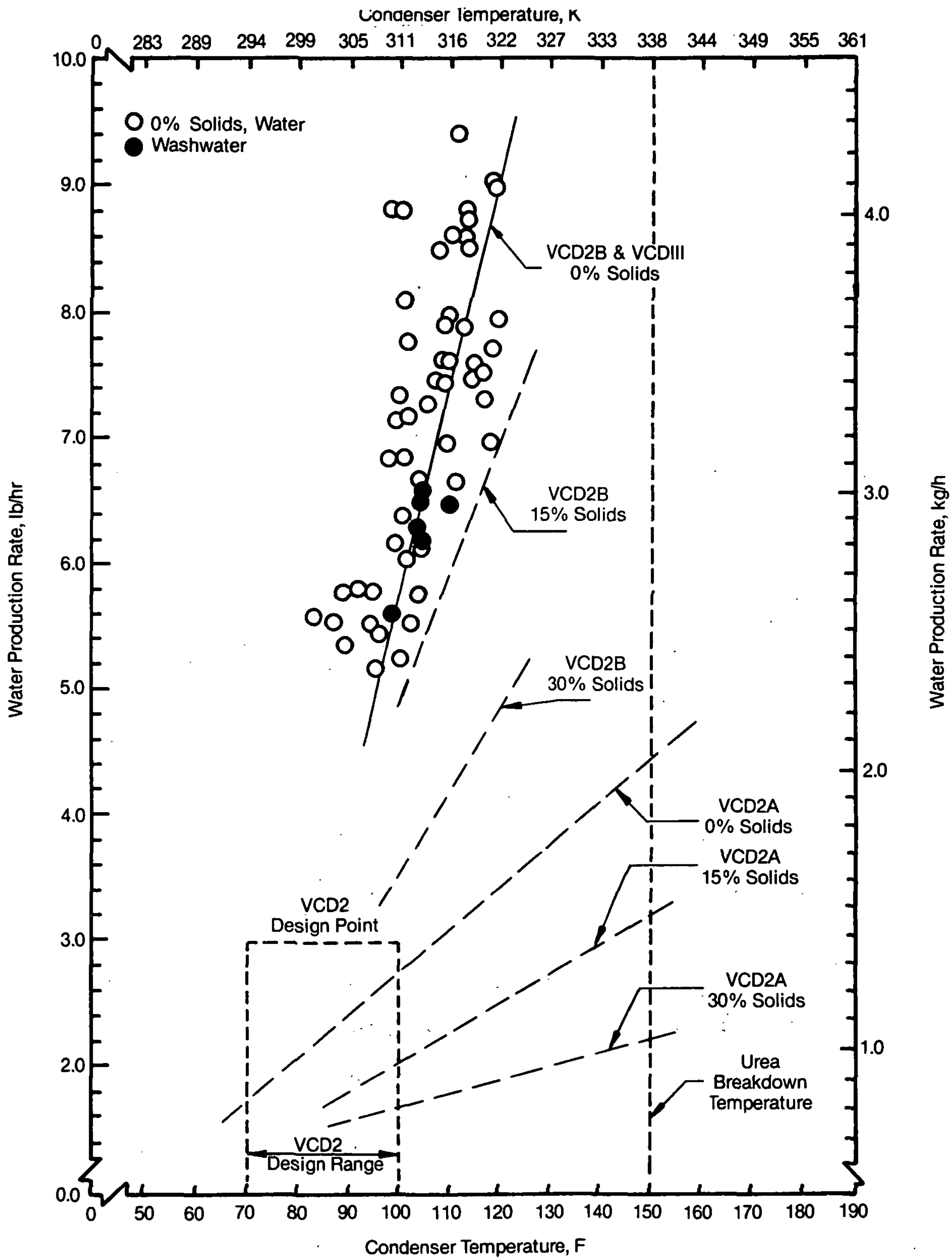


FIGURE 13 VCDS WATER PRODUCTION RATE VERSUS CONDENSER TEMPERATURE (1985 AND 1986 (WITH WASHWATER) TEST RESULTS)

4. Water Production Rate versus Fluids Pump Speed--Previous optimization testing performed with the VCD2A during early 1985 indicated that fluids pump speed has a significant effect upon water production rate (1, 5). The fluids pump controls the amount of wastewater covering the evaporator surface, affecting waste fluid film thickness, condenser-to-evaporator heat transfer and, therefore, water production rate.

   The VCD2A parametric testing revealed the operating curves shown in Figure 14. The relationship between water production rate as a function of fluids pump speed and recycle loop solids at a constant 316 K (110 F) condenser temperature is defined as follows:

   - The skewed parabolic shape of each operating curve is due to the effect of fluids pump speed upon evaporator film formation. Pump speeds below the optimum decrease water production rate, due to the incomplete film coverage of the evaporator surface. Pump speeds greater than optimum create an excess film thickness which inhibits heat transfer.

   - The optimum fluids pump speed range for maximized water production rate was found to be 0.31 to 0.73 rad/sec (3 to 7 rpm) for 0% to 30% solids, as defined by the solid data points in Figure 14.

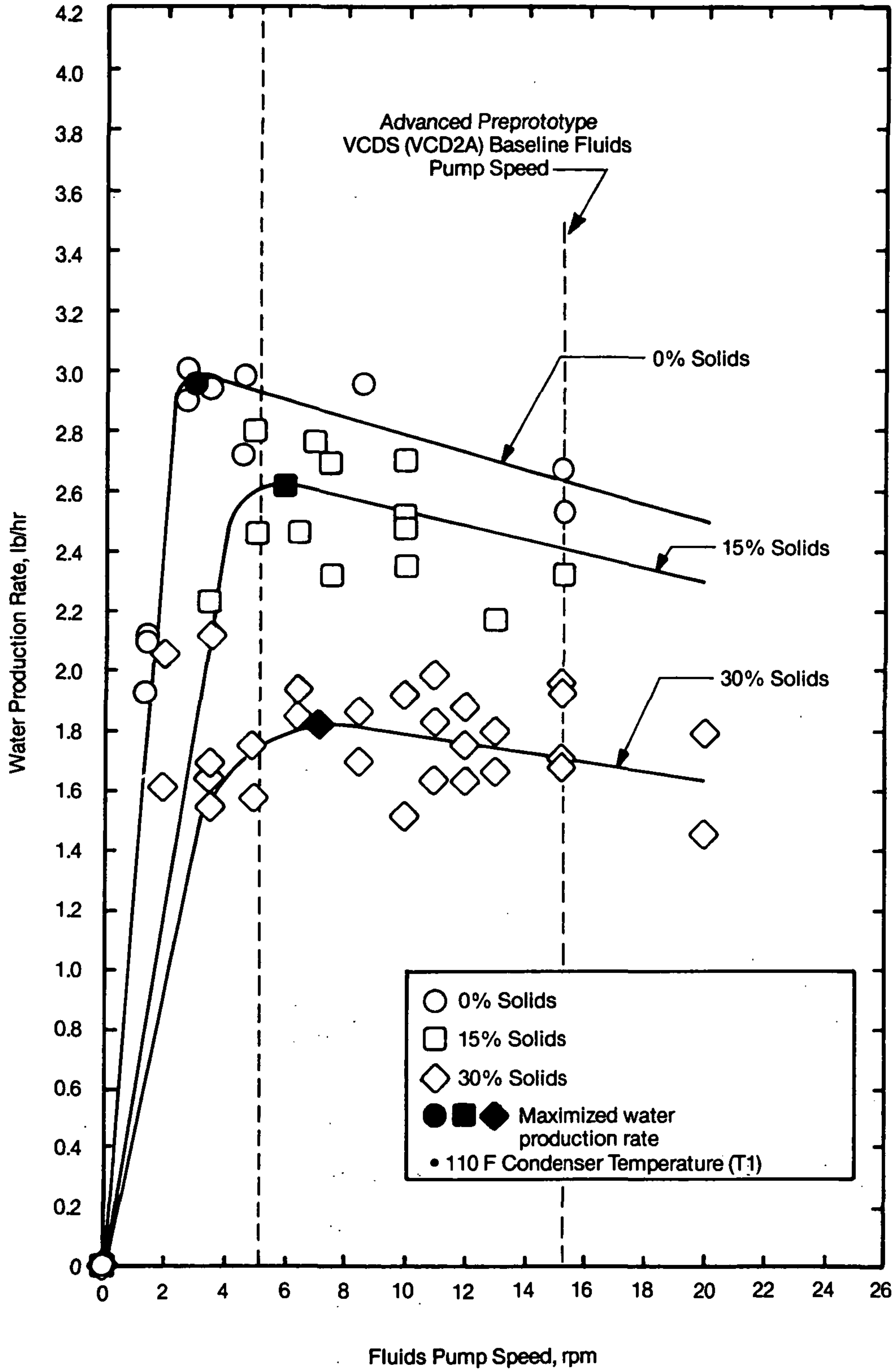
   - The average optimum fluids pump speed of 0.52 rad/sec (5 rpm) for 0% to 30% solids permits a 10% improvement in water production rate when compared to the original pump speed (1.59 rad/sec (15.2 rpm)).

   A previous recommendation to continuously vary fluids pump speed as a function of solids concentration does not seem warranted because increased pump controller complexity would yield only slight gains (5). However, reduction of the fluids pump speed from the original 1.59 rad/sec (15.2 rpm) baseline value to 0.53 rad/sec (5 rpm) results in a 300% increase in pump tubing life because of less tube flexures per unit time. As a result of this test data, an equivalent 10,000-hour life fluids pump tube design has been demonstrated.

   The VCD2B parametric testing had indicated similar relationships between water production rate as a function of fluids pump speed and recycle loop solids (see Figure 15). Results are as follows:

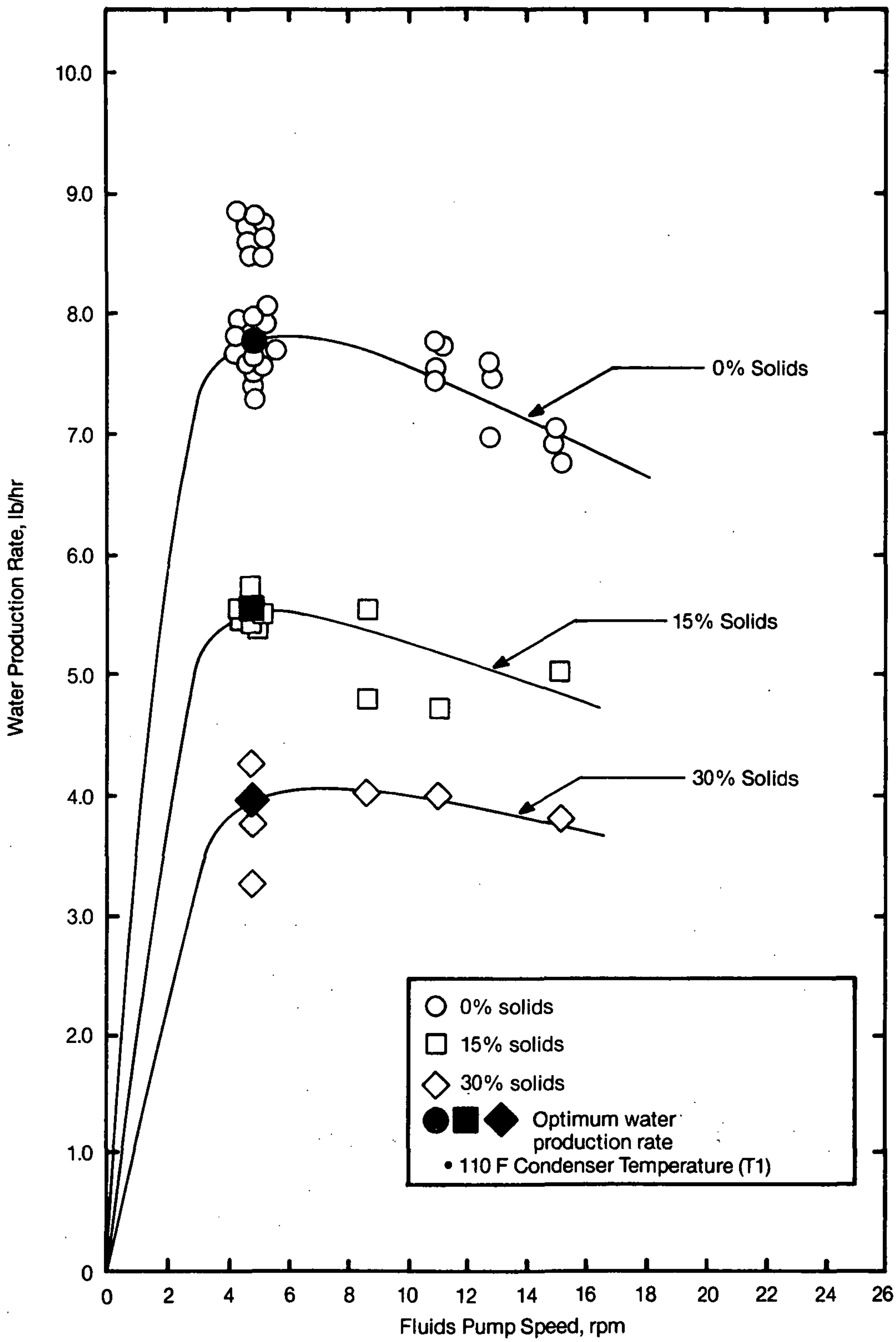
   - Optimum fluids pump speed range for maximized water production rate: 3 to 7 rpm (0 to 30% solids).

   - Average optimum fluids pump speed: 5 rpm.



(a) • At constant condenser temperature of 110 F
• VCD2A parametric test nos. 29, 30 and 31 data

FIGURE 14 VCDS WATER PRODUCTION RATE VERSUS FLUIDS PUMP SPEED[(a)]



(a) • Based on VCD2B & VCD III parametric test program
• At constant condenser temperature of 110 F

FIGURE 15 VCDS WATER PRODUCTION RATE VERSUS FLUIDS PUMP SPEED (1986 TEST RESULTS)[a]

- Reduction of fluids pump speed from 15.2 rpm to 5 rpm will result in:

  - 300% increase in fluids pump tubing life (less tube flexures per unit time)
  - 11% increase in water production at 0% solids
  - 10% increase in water production at 15% solids
  - 1% increase in water production at 30% solids

- Controlling fluids pump speed as a function of solids concentration does not seem warranted (increased controller complexity versus only slight gains).

5. Specific Energy versus Condenser Temperature--Figure 16 depicts the relationship between the VCD2A specific energy as a function of condenser temperature and recycle loop solids. The following comments apply:

   - Specific energy decreases by up to 75% as condenser temperature increases from 70 to 150 F.

   - Operating curve at 0% solids best characterized due to extensive body of data available (1983 through 1985).

   - General shape of operating curves at 15% and 30% solids based upon basic shape of curve at 0% solids and most recent data generated.

   For the VCD2B, a similar figure (Figure 17) indicates:

   - Specific energy decreases by up to 45% as condenser temperature increases from 75 to 125 F.

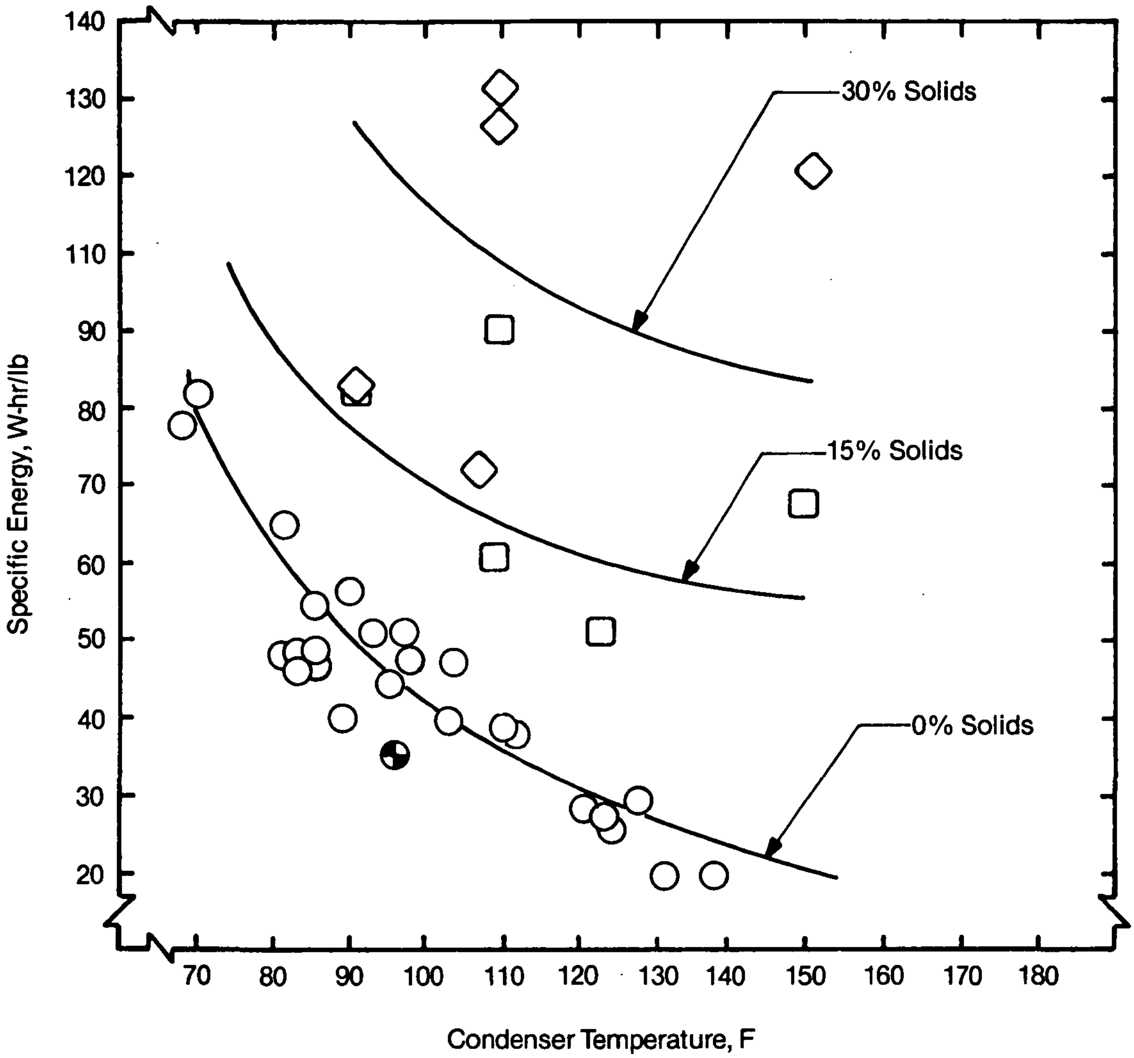
   - VCD2B specific energy values are slightly lower than VCD2A (i.e., 34 W-hr/lb versus 37 W-hr/lb at 110 F, 0% solids), but VCD2B water production rate is approximately three times that of VCD2A.

6. Additional VCD2B Parametric Test Results--During the VCD2B parametric testing, additional data analysis was completed. The following is a summary of the major results:

   a. VCD2B Water Production versus Power (see Figure 18)--The following conclusion can be made:

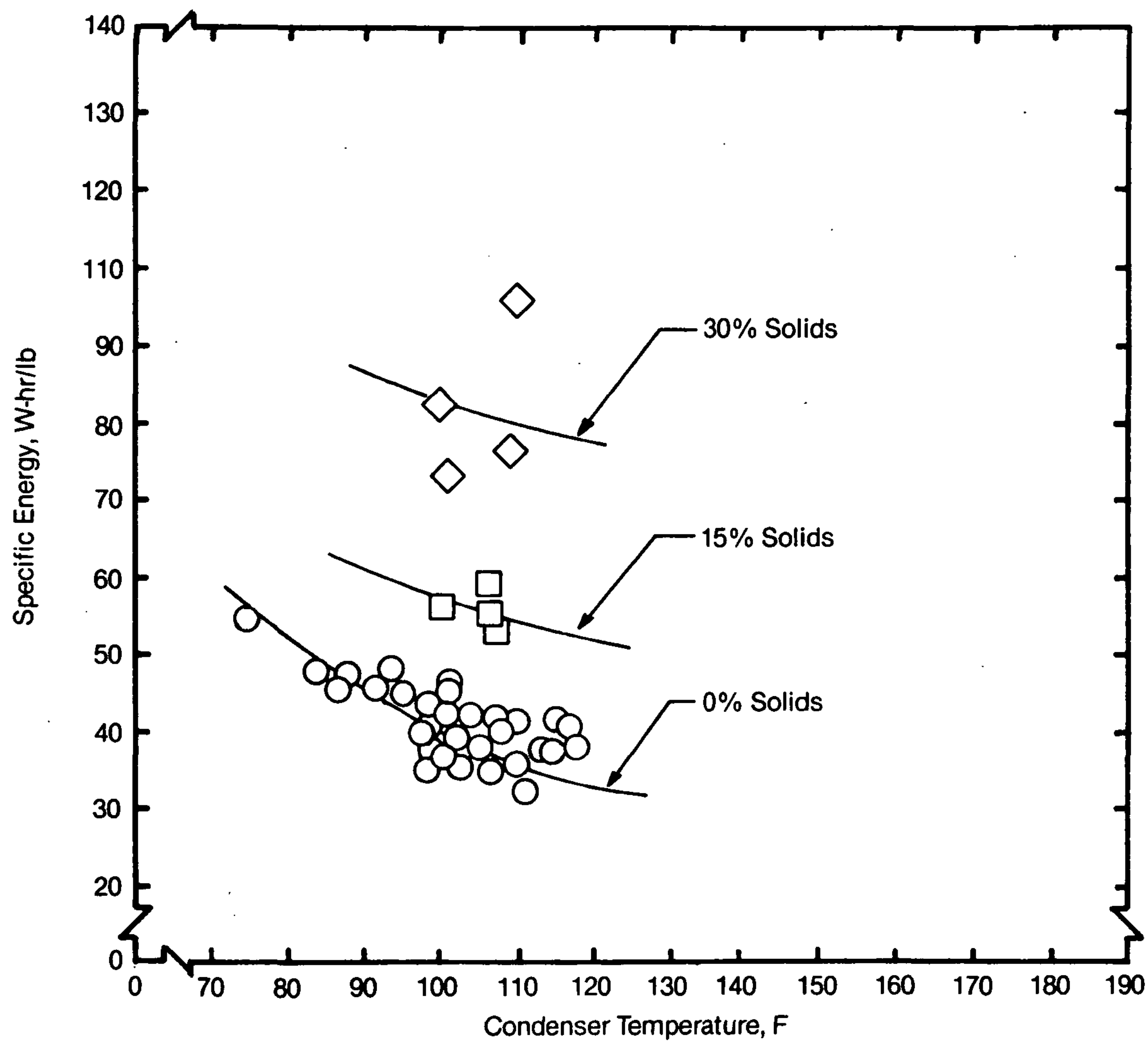
      - Water production rate versus power is a linear function.

      - Compressor performance is indicated by water production-power relationship, therefore, also a linear function.



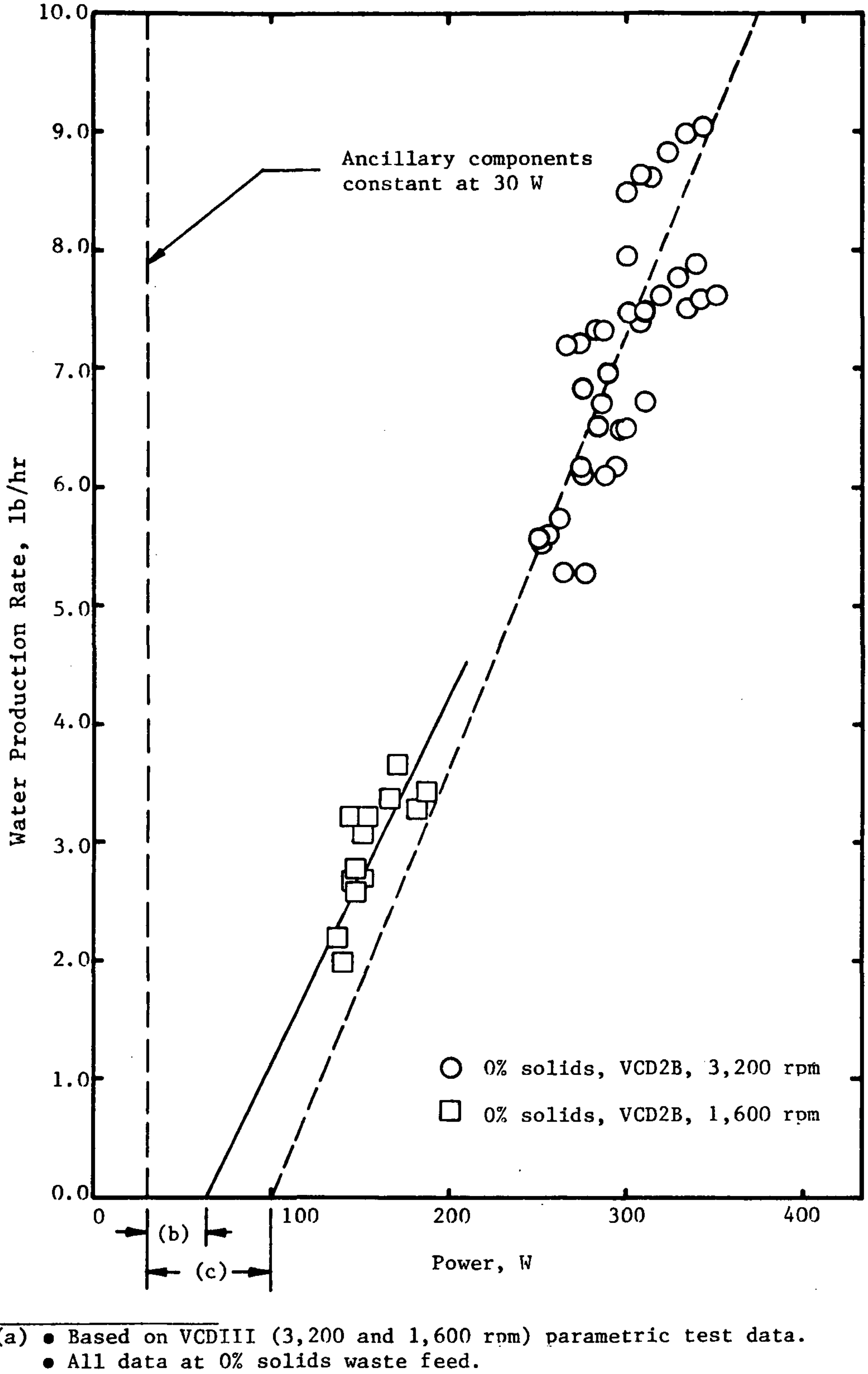
(a) • VCD2A parametric test program
• VCD2A baseline fluids pump speed of 15.2 rpm
• Specific energy based upon basic VCD2A process hardware

FIGURE 16 VCDS SPECIFIC ENERGY VERSUS CONDENSER TEMPERATURE[(a)]



(a) • Specific energy based on VCD2B & VCD III parametric test program
• Baseline fluids pump speed of 5.0 rpm

FIGURE 17 VCDS SPECIFIC ENERGY VERSUS CONDENSER TEMPERATURE (1986 TEST RESULTS)[a]



(a) • Based on VCDIII (3,200 and 1,600 rpm) parametric test data.
• All data at 0% solids waste feed.
(b) VCD2B, 1,600 rpm frictional losses, 31.5 W.
(c) VCD2B, 3,200 rpm frictional losses, 68.5 W.

FIGURE 18 VCDS WATER PRODUCTION RATE VERSUS POWER[(a)]

- Ancillary components required 30 W (constant) of power, independent of water production.

- Frictional losses for VCD2B, 1,600 and 3,200 rpm are 31.5 and 68.5 W (constant), respectively.

b. VCD2B Evaporator Pressure versus Evaporator Temperature (see Figure 19)--The following conclusions can be made:

- Relationship between evaporator pressure and temperature is indicative of the saturation steam curve.

- As temperature increases (70 to 110 F), the evaporator pressure and temperature relationship more closely resembles the saturation steam curve, indicating equilibrium conditions have been met within the evaporation region.

- At lower temperatures (70 to 85 F), data departs from the saturation steam curve, indicating equilibrium conditions have not been met and the evaporator region is in a state of transition from subcooled and not wetted to saturated and fully wetted.

c. VCD2B Condenser Pressure versus Condenser Temperature (see Figure 20)--Condenser pressure and temperature relationship depicts a consistent shift to the right of the saturation steam curve. This phenomenon may be due to possible superheated steam and/or condenser temperature sensor location is in an area where superheated steam would exist.

d. VCD2B Water Production Rate versus Differential Temperature (see Figure 21)--The following conclusions can be made:

- High water production rate corresponds to an optimum differential temperature range (12 to 14 F).

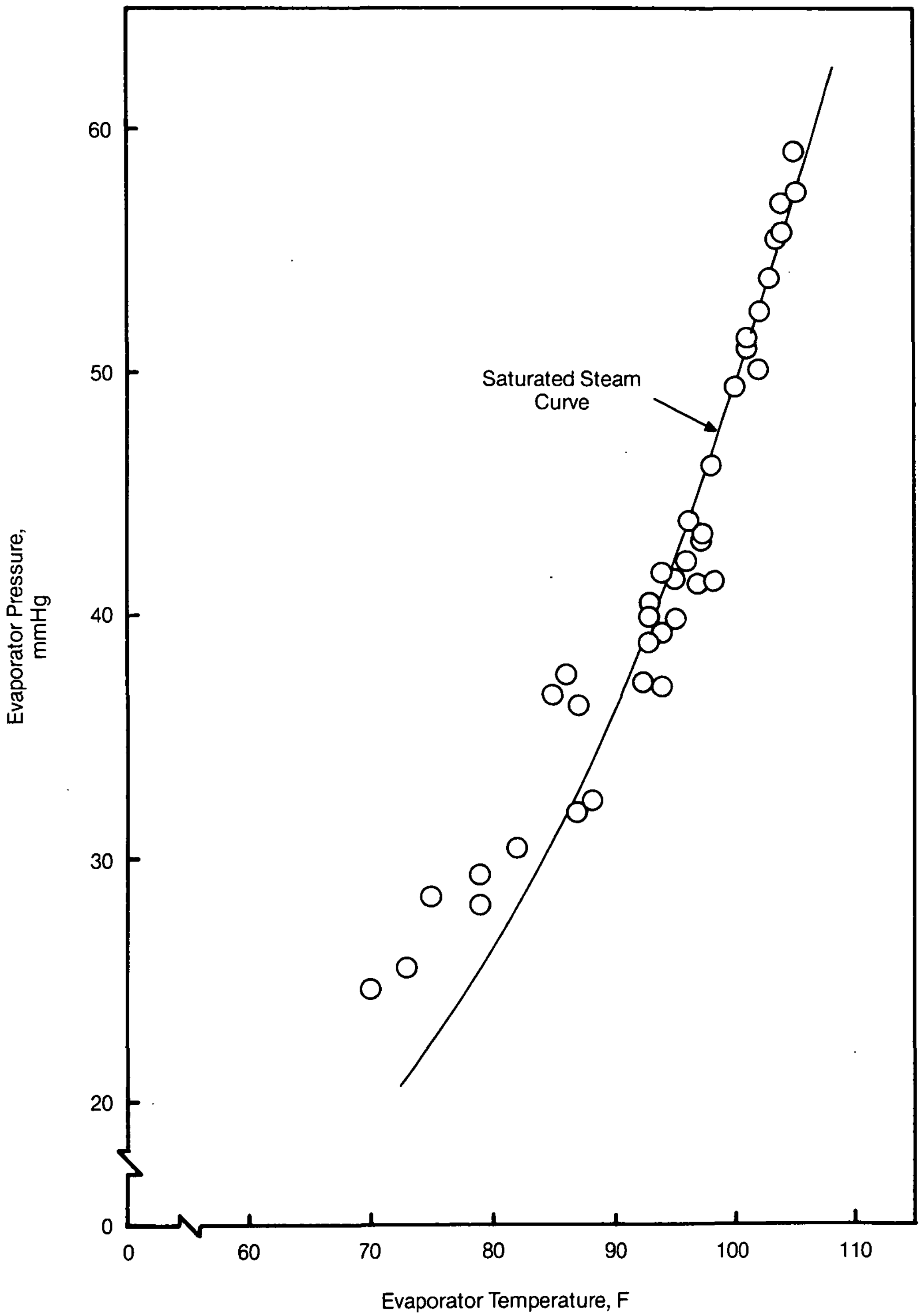
- Increasing the differential temperature (greater than 14 F) does not appear to increase water production rate.

- A range with an upper and lower limit is evident and may correspond to other factors such as differential pressure, subsystem purging, etc.

e. VCD2B Water Production Rate versus Differential Pressure (see Figure 22)--The following conclusions can be made:

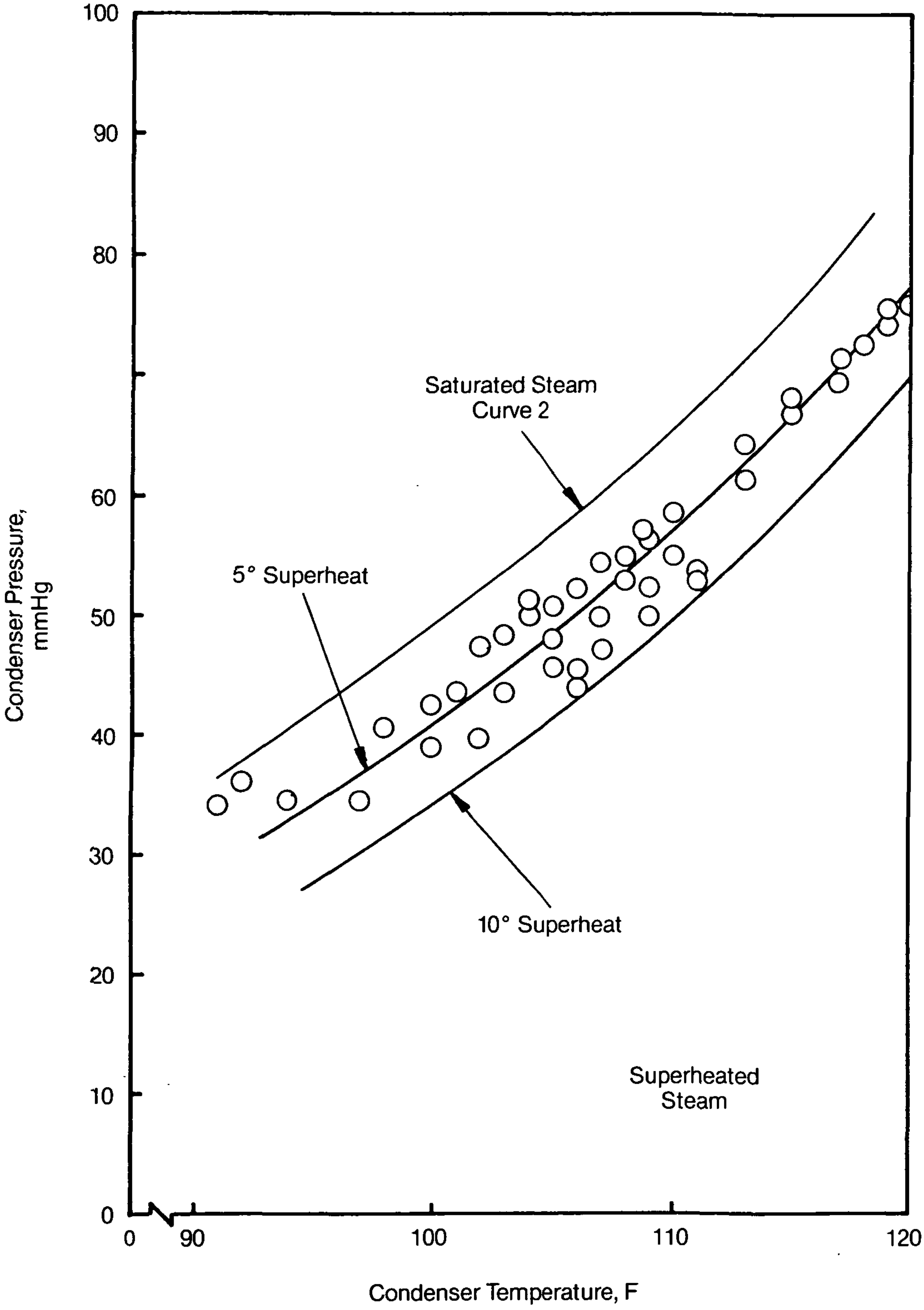
- High water production rates correspond to an optimum differential pressure range (13 to 15 mmHg).

- Increasing the differential pressure (greater than 16 mmHg) does not appear to increase water production rate.



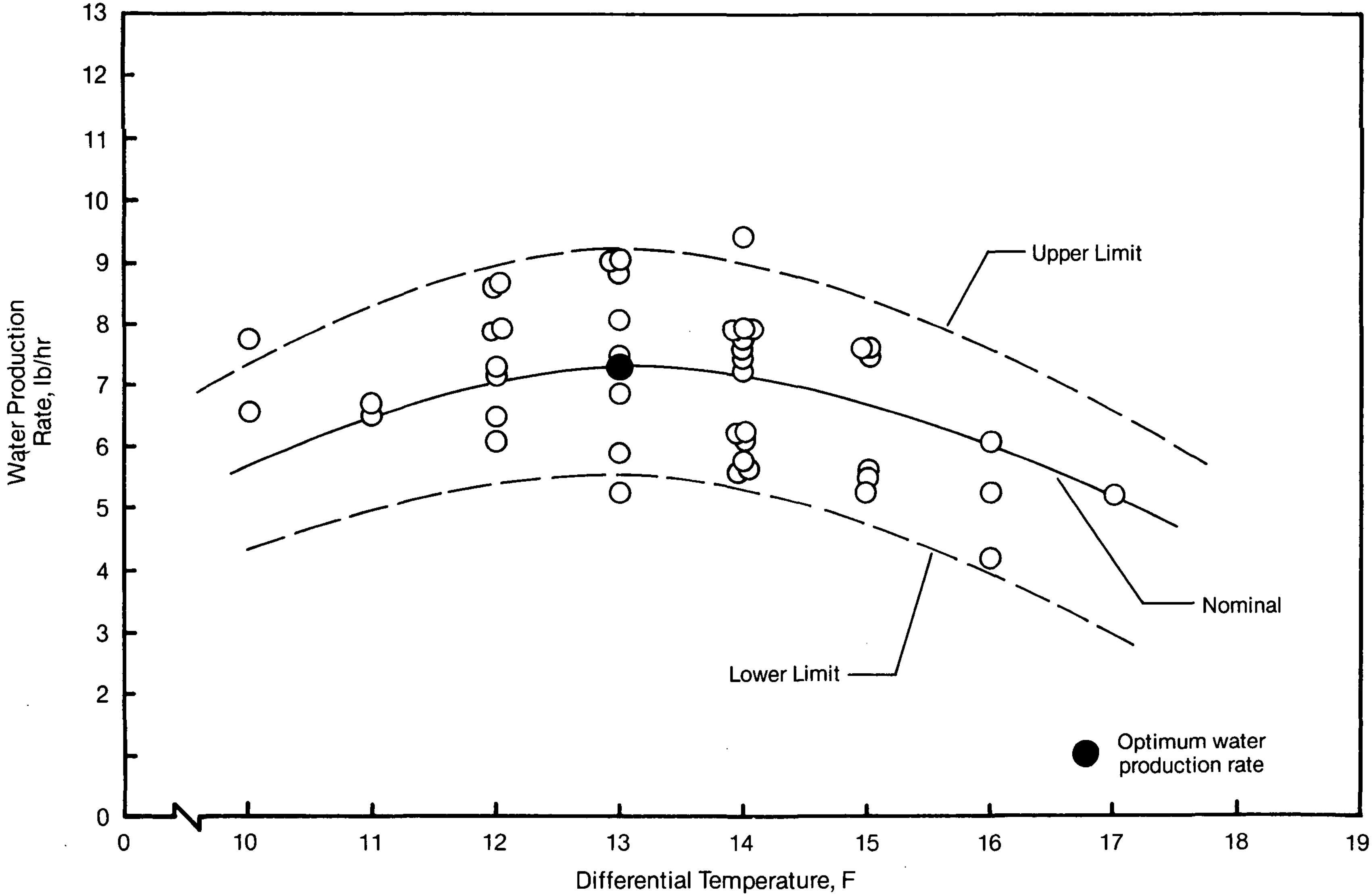
(a) • 1986 Data with VCD III
• All Data with 0% Solids Waste Feed

FIGURE 19 VCDS EVAPORATOR PRESSURE VERSUS EVAPORATOR TEMPERATURE[(a)]



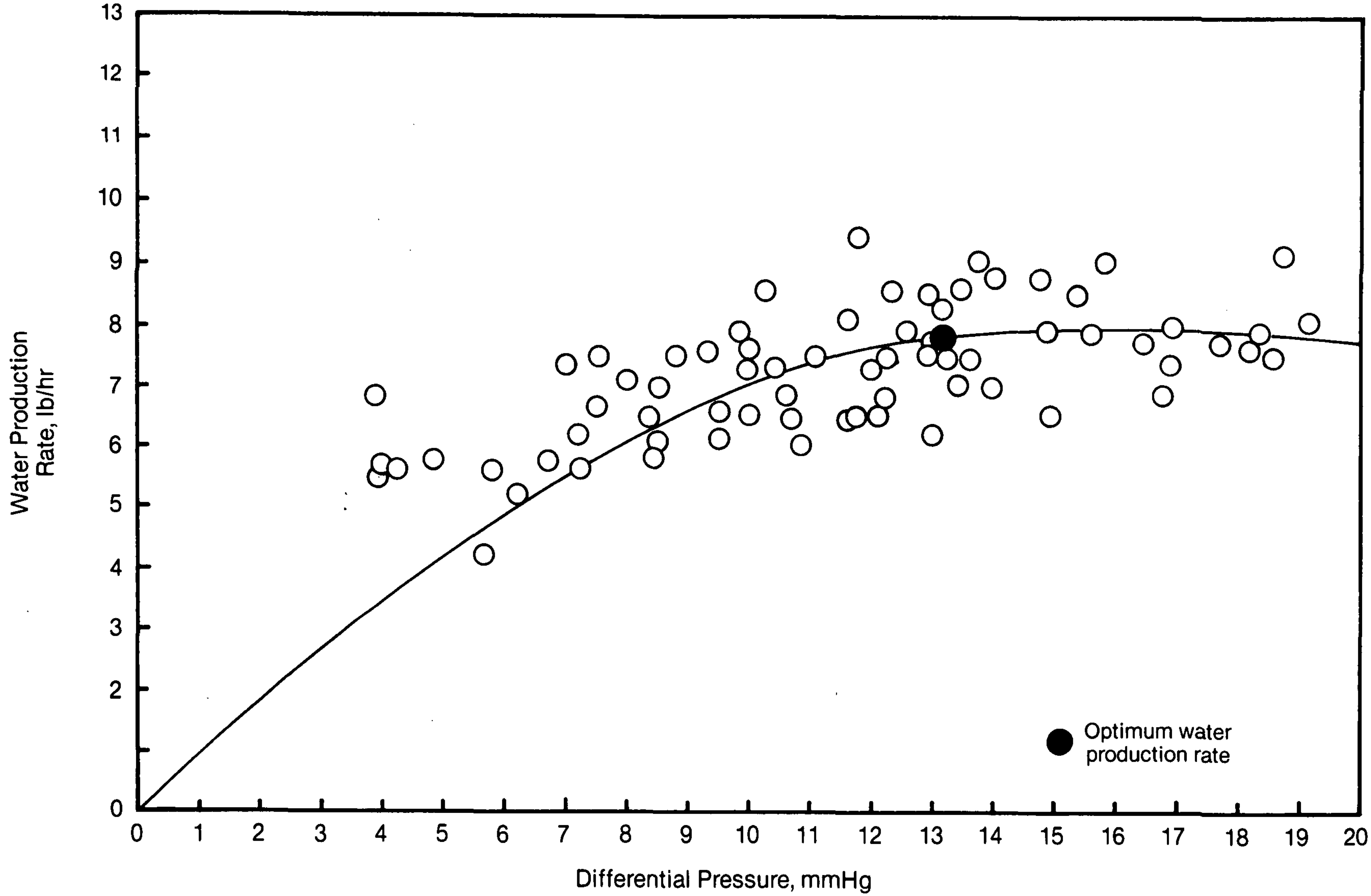
(a) • 1986 Data with VCD III
• All Data with 0% Solids Waste Feed

FIGURE 20 VCDS CONDENSER PRESSURE VERSUS CONDENSER TEMPERATURE[a]



(a) • 1986 Data with VCD III
• All Data with 0% Solids Waste Feed
• Differential Temperature is from Condenser to Evaporator Regions

FIGURE 21 VCDS WATER PRODUCTION RATE VERSUS DIFFERENTIAL TEMPERATURE[(a)]



(a) • Combined 1986 Data for VCD2B and VCD III
• All Data at 0% Solids Waste Feed
• Differential Pressure is Across L/D = 1 Compressor

FIGURE 22 VCDS WATER PRODUCTION RATE VERSUS DIFFERENTIAL PRESSURE[(a)]

- A range is evident and may correspond to other factors such as differential temperature, subsystem purging, etc.

Summaries of the VCD2A and VCD2B parametric testing have been presented in Tables 6 and 7, respectively.

Optimum Operating Conditions and Characteristics of VCDS

Optimum operating conditions and characteristics were defined, based upon the parametric testing results. A summary of the VCD2A and VCD2B optimum operating conditions and characteristics has been presented in Table 8.

Post-Test Refurbishment of VCDS

The variety of tests performed with the VCD (VCD2A and VCD2B) subsystem during the contractual test program brought the total operating time in all modes to 22,753 hours (based on distillation unit demonstrated life), with 10,217 hours of operation in the Normal mode. The total operating time in all modes includes the Shutdown mode and Normal mode as well as hardware rotating hours in Reprocessing mode, Partial drydown mode and all mode transitions. It should be noted that operating time in the Shutdown mode represents operation of the C/M I hardware and software. All subsystem hardware is also exposed to the VCDS environment in the Shutdown mode. Therefore, operating hours accumulated in the Shutdown mode are a vital portion of the subsystem evaluation. During the Shutdown mode, the software is active and all sensors are powered. Table 9 presents the VCDS component life summary.

The VCDS was disassembled prior to the VCD2A parametric test and after each parametric test program. The purpose of this disassembly was to inspect the hardware for any signs of wearout, corrosion, etc. All inspections in general indicated little to no component wearout or corrosion. The following observations were made prior to the VCD2A parametric test:

- The centrifuge bearings turned freely by hand without binding.

- Examination revealed that the June 1984 refurbishment of the centrifuge compressor-end bearing mounting hub, involving welding and finish machining of its bearing and sealing surface, was successful showing no wear problem.

- No rubbing between the centrifuge drive timing belt and distillation unit end plate was found, indicating that the June 1984 refurbishment relief machining of the distillation unit end plate was successful.

- The centrifuge liquid level sensor (L1) and combination evaporator temperature sensor (T2) were found in excellent condition with no signs of precipitate buildup.

- All wetted surfaces of the demister were found to be in excellent condition and not coated with precipitate.

TABLE 6 VCD2A PARAMETRIC TEST RESULTS SUMMARY

Parametric Test Parameter Ranges	
• Temperature, F	90 to 150
• Dissolved Solids Concentration, %	0 to 62
• Fluids Pump Speed, rpm	1.0 to 20.0
Low Dissolved Solids Test Results	
• Water Production Rate, Maximum, lb/hr	6.5
• Condenser Temperature, F	162
• Dissolved Solids Concentration, Maximum, %	2.3
• Fluids Pump Speed, rpm	15.2
High Dissolved Solids Test Results	
• Water Production Rate, lb/hr	2.72
• Temperature, F	150
• Dissolved Solids Concentration, %	62
• Fluids Pump Speed, rpm	15.2
• Product Water Quality (w/o Post-Treatment)	
- pH	3.29
- Conductivity, mmhos/cm	69
- NH_3, ppm	0.66
- TOC, ppm	20

TABLE 7 VCD2B PARAMETRIC TEST RESULTS SUMMARY - 1986

• Current operating time, hr	2,160[(a)]
• Concentration range, %	0 to 30
• Average temperature, F	110
• Average specific energy, W-hr/lb	42
• Average water quality	
– From urine, without post-treatment	
• pH	3.48
• Conductivity, µmhos/cm	46
• NH_3, ppm	0.32
• Organic carbon, ppm	12
– From urine, with post-treatment	
• pH	7.14
• Conductivity, µmhos/cm	81
• NH_3, ppm	0.02
• Organic carbon, ppm	TBD[(b)]
– From STS washwater, without post-treatment	
• pH	3.86
• Conductivity, µmhos/cm	24
• NH_3, ppm	0.08
• Organic carbon, ppm	13
– From commercial washwater, without post-treatment	
• pH	5.31
• Conductivity, µmhos/cm	8
• NH_3, ppm	-

(a) Time in Normal mode as of 11:20 a.m. EST, 10/24/86.

Table 7 - continued

Parametric Test Parameter Ranges	
• Temperature, F	90 to 140
• Dissolved solids concentration, %	0 to 30
• Fluids pump speed, rpm	5.0 to 17.5
Low Dissolved Solids Test Results	
• Water Production Rate, Maximum, lb/hr	9.5
• Condenser Temperature, Maximum, F	123
• Dissolved Solids Concentration, %	0 to 4
• Fluids Pump Speed, rpm	5.0
High Dissolved Solids Test Results	
• Water Production Rate, lb/hr	4.28
• Temperature, F	107
• Dissolved Solids Concentration, %	30
• Fluids Pump Speed, rpm	5.0
• Product Water Quality (w/o Post-treatment)[a]	
- pH 3.38	
- Conductivity, µmhos/cm	51
- NH_3, ppm	0.43
- TOC, ppm	13

(a) Water recovery from pretreated urine.

TABLE 8 DEFINITION OF OPTIMUM VCD2A AND VCD2B OPERATING CONDITIONS/CHARACTERISTICS

	Original Baseline VCD2A[(a)]	Optimized VCD2A[(b)]	VCD2B[(c)]
Condenser Temperature (T1), F			
Range	90 to 100	90 to 150	90 to 150
Nominal	90	110	110
Fluids Pump Speed (S2), rpm			
Range	15.2	3.0 to 7.0	3.0 to 7.0
Nominal	15.2	5.0	5.0
Drive Amperage, A			
Range	4.4 to 4.55	4.4 to 7.75	8.2 to 12.2
Nominal	4.4	5.0	10.0
Specific Energy, W-hr/lb			
Range	46 to 42	46 to 23	43 to 32
Nominal	46	37	35
Recycle Loop Solids, %			
Range	0 to 50	0 to 50	0 to 30
Nominal	25	25	15
Water Production Rate, lb/hr			
Range	2.5 to 1.6	3.2 to 1.83	9.5 to 5.2
Nominal	2.5	2.3	7.8
Product Water Discharge Temperature, F	84±2	94±2	92±2
Product Water Quality			
From urine			
Conductivity, μmho/cm	63[(d)]	57[(d)]	46[(d)]/81[(e)]
Ammonia, ppm	0.3[(d)]	0.5[(d)]	0.3[(d)]/0.02[(e)]
pH	3.7[(d)]	3.4[(d)]	3.5[(d)]/7.1[(e)]
TOC, ppm	15[(d)]	13[(d)]	12[(d)]
From washwater			
Conductivity, μmho/cm	-	-	24[(f)]/8[(g)]
Ammonia, ppm	-	-	0.1[(f)]
pH	-	-	3.9[(f)]/5.3[(g)]
TOC, ppm	-	-	13[(f)]
Condenser Pressure (P1), mmHg	36 to 55	36 to 185	36 to 80
Condenser Delta P (P2), mmHg	1.8 to 3.1	1.8 to 10.2	13 to 15
Condenser/Evaporator Delta T, F	4 to 6	4 to 6	12 to 14
Centrifuge Speed (S3), rpm	230 to 250	230 to 250	230 to 250
Compressor Speed (S1), rpm	3,200	3,200	3,200

(a) Pre-1985.
(b) Per 1985 Parametric Test Program.
(c) Per 1986 Parametric Test Program including VCD III data.
(d) Prior to post-treatment, average values.
(e) After post-treatment, average values.
(f) From STS washwater, prior to post-treatment, average values.
(g) From commercial washwater, prior to post-treatment, average values.

TABLE 9 VCDS COMPONENT LIFE SUMMARY[a]

Component	Demonstrated Life, hr: Direct Exposure to Environment[b]	Demonstrated Life, hr: In Normal Mode
• Distillation Unit	22,753	10,217
- Stationary Structures - Evaporator/Condenser Centrifuge - Compressor - Demister		
• Liquid Level Sensor	21,553	9,017
• Still Drive Motor	9,865	7,717
• Fluids Pump	22,753	9,217
• Peristaltic Tubing	21,873	9,217
• Waste Storage Tank	18,953	9,017
• Recycle/Filter Tank	15,253	9,017
• Ancillary Components[c]	20,733	8,197

(a) Accumulated life as of 4:00 p.m. EDT, 11/12/86.
(b) Accumulated time in all operating modes including Shutdown mode, Normal mode and hardware rotating hours in Reprocessing mode, Partial Drydown mode and all mode transitions.
(c) Motor-driven valves, check valves, sensors and subsystem plumbing.

TEST STAND DESIGN AND DEVELOPMENT

A major task of this program was the design and development of two test stands to allow for the continued development and endurance testing of two key VCDS components - the rotary lobe compressor and fluids pump assemblies. Each test stand was successfully designed, fabricated, tested and delivered to NASA JSC.

The Compressor Test Stand (CTS) was designed to support characterization and endurance testing of the VCDS compressor with its magnetic drive coupling and still drive motor. The Fluids Pump Test Stand (FPTS) was designed to support the characterization and endurance testing of the VCDS fluids pump with its integral gearmotor drive assembly and peristaltic tubing.

The following design guidelines for each test stand were set at the beginning of the development effort and were successfully met:

- Each test stand must be self-contained, requiring only standard fluid and power interfaces for operation.

- Allow testing of the test article (key VCDS component) must be in a representative environment (such as temperature and pressure) as if the items were operating as part of an actual VCD subsystem.

- Permit continuous 24-hour per day operation with automatic safe shutdown in the event of a test stand or test article failure.

- Contain adequate instrumentation to evaluate the performance of the test article and of the test stand itself, with provisions for an interface to customer-provided automatic data acquisition equipment, where applicable.

Both test stand design efforts were conducted in parallel in order to standardize basic hardware such as the fluid storage tanks, test stand structural frame, main control panel and some of the test instrumentation. The generic design features minimized normal maintenance time for each test stand. In particular, each test stand has the following maintainability features:

- Clear acrylic tank bodies to permit visual inspection of tank interiors.

- Capped access ports upstream and local to fluids pump test article to permit initial fluid line priming.

- Fluid supply line check valves installed local to fluid tanks to maintain liquid line prime.

- Drain valves on all fluids tanks.

- All plumbing lines standardized to 3/8 inch stainless steel tubing.

An improved (L/D = 1) compressor with radial magnetic drive and brushless DC motor and baseline fluids pump with an external harmonic drive assembly (and support framing) was provided with the CTS and FPTS, respectively.

Each test stand underwent a limited test program prior to its scheduled delivery to NASA JSC. The test program included checkout and shakedown testing to ensure integrated test stand operation with its respective test article. Following the shakedown test, a mini-characterization test of each test article was also performed as a function of key VCDS operating parameters such as pressure, temperature, flowrate and rotating speed.

Technical documentation delivered with each test stand to NASA JSC included as-built drawings, Operations/Maintenance and Repair Manuals, Failure Modes and Effects Analysis (FMEA) and Nonmetallic Materials List.

The following two report sections provide further details regarding the Compressor and Fluids Pump Test Stands.

Compressor Test Stand

The CTS is a self-contained unit capable of permitting long-term VCDS compressor evaluation at simulated VCDS operation conditions. Figure 23 shows the test stand. The CTS consists of a Compressor Test Chamber (CTC) which contains a stacked evaporator tray to simulate the VCDS evaporator, a rotary lobe compressor test article to compress the water vapor and a water cooled condenser heat exchanger which minimizes the backpressure effect on the test compressor. A functional schematic of the CTC is shown in Figure 24 with major system components identified. Table 10 summarizes the four operating modes of the CTS.

From a systems packaging standpoint, the CTS:

- Is a six-foot test stand bench with extra support frame reinforcement.
- Has an estimated maximum combined tank/fluid weight of 140 lb.[a]
- Has an estimated CTC weight of 200 lb.
- Has the fluid tank located below to provide test stand low center of gravity.
- Has the fluid tank support structure standardized for CTS and FPTS.

Intrinsic safety features designed into the test stand include:

- Tank volume sized twice the nominal tank design liquid level to prevent overfilling.
- Backpressure regulator in parallel with pump motor to provide pump pressure control/protection.

(a) Tank assumed filled to capacity.

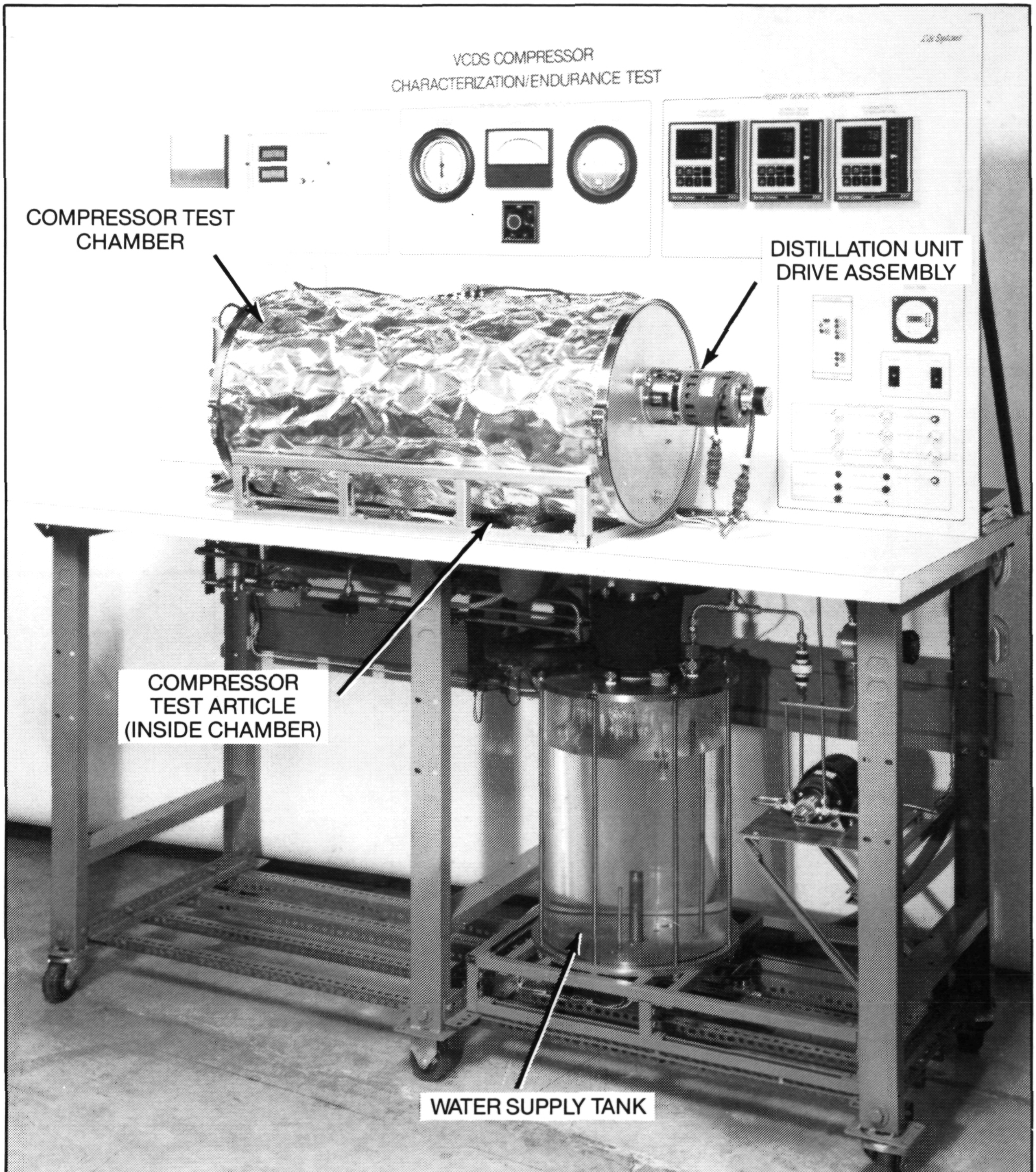


FIGURE 23 VCDS COMPRESSOR CHARACTERIZATION/ENDURANCE TEST STAND

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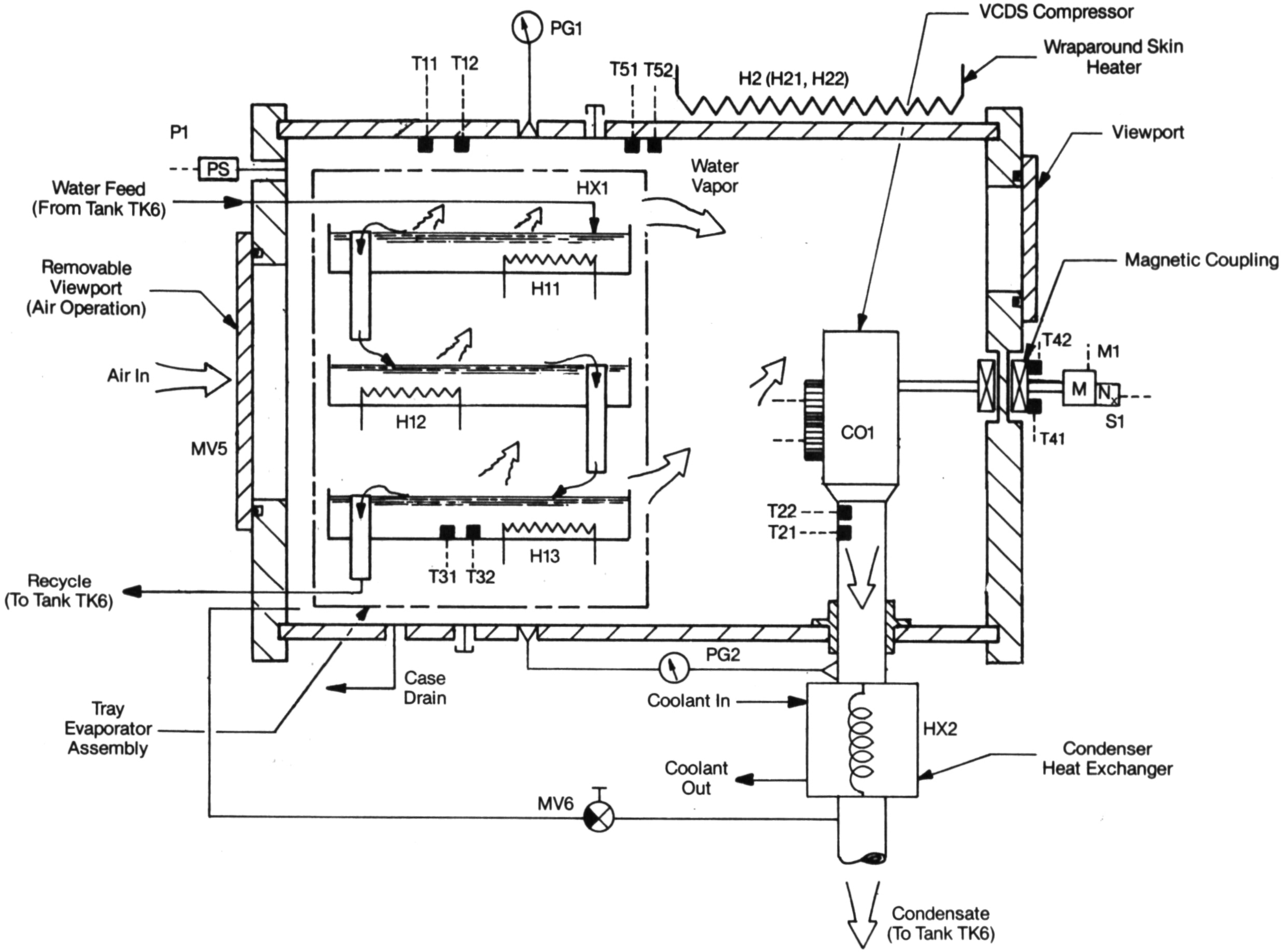

FIGURE 24 COMPRESSOR TEST CHAMBER FUNCTIONAL SCHEMATIC

TABLE 10 CTS OPERATING MODES AND UNPOWERED MODE DEFINITIONS

Mode (Code)	Definition
Shutdown (B)	The CTS is not pumping any vapor. The compressor is stopped and all the actuators are de-energized. The test stand is powered and all sensors are working. The Shutdown mode is called for by: • Manual actuation • High or low evaporator temperature (T3) • High Water tank temperature (TS1) • High chamber wall temperature (T5) • Low water level in water storage tank (L1) • Power failure of still motor and pump motor (M1, M2) • Low compressor speed
Normal (A)	The CTS is performing its function of compressing gas vapor then condensing it to water. The Normal mode is called for by: • Manual actuation • Auto restart after a power on
Standby (E)	The CTS is ready to perform its function. The system is powered. The temperature of vapor is at operating condition. Both still drive motor and pump motor are off. This mode can be called for by: • Manual actuation
Unpowered (D)	No electrical power is applied to the test stand. The Unpowered mode is called for by: • Manual actuation • Electrical power failure

- All solenoid valves provided with manual override via actuator override control panel switches.

The CTC is completely sealed and is provided with external temperature and pressure control to maintain simulated VCDS operating conditions. Provisions also exist for testing of the VCDS radial magnetic drive assembly and still drive motor in conjunction with the compressor.

Figure 25 depicts the VCD2A L/D = 0.62 compressor. The new VCD2B L/D = 1 compressor is similar to this unit, but contains four-inch long lobes and a corresponding length change in the compressor casing.

The front control panel for the test stand is subdivided into six main sections.

- Test Stand Control
- Heater Control/Monitor
- Compressor Chamber Monitor
- Compressor Drive Monitor
- Flow Monitor
- Compressor Test Stand Mechanical Interface

The function of the Test Stand Controller (TSC), located in the right-hand portion of the front panel, is to control overall test stand operation, including main electrical power control, accumulation of operating time and automatic protection and shutdown control.

Shutdown signals are routed to a Control/Shutdown Status Panel which indicates which parameter initiated the shutdown. Alarm indications are provided for chamber wall temperature (T5), water temperature (T8) and water level (L1) in CTS tank, evaporator temperature (T3) and compressor speed (S1). A reset switch is provided to clear the Shutdown Status Panel. A shutdown initiated by any of the five parameters monitored will result in a shutdown signal being sent to the Control/Shutdown Status Panel. The shutdown signal will enable the appropriate indicator lamp and the Status Panel will then "latch" the lamp so that it remains lit in the event the alarm condition disappears. Additional shutdown signals initiated by other parameters will be received by the Status Panel, but will not immediately enable the indicator lamps due to the shutdown latching mechanism; thus, visibility for the parameter which initiated the shutdown is maintained. When the Status Panel reset switch is triggered, the latching mechanism is disabled and the shutdown signals received will the enable the appropriate indicator lamps.

In addition, the Control/Shutdown Status Panel has an indication lamp to provide the status of the CTC pressure control via pressure switch (P1). The status lamp indicates that the pressure control is functioning properly. Failure of the lamp to light can therefore be used to troubleshoot a control problem.

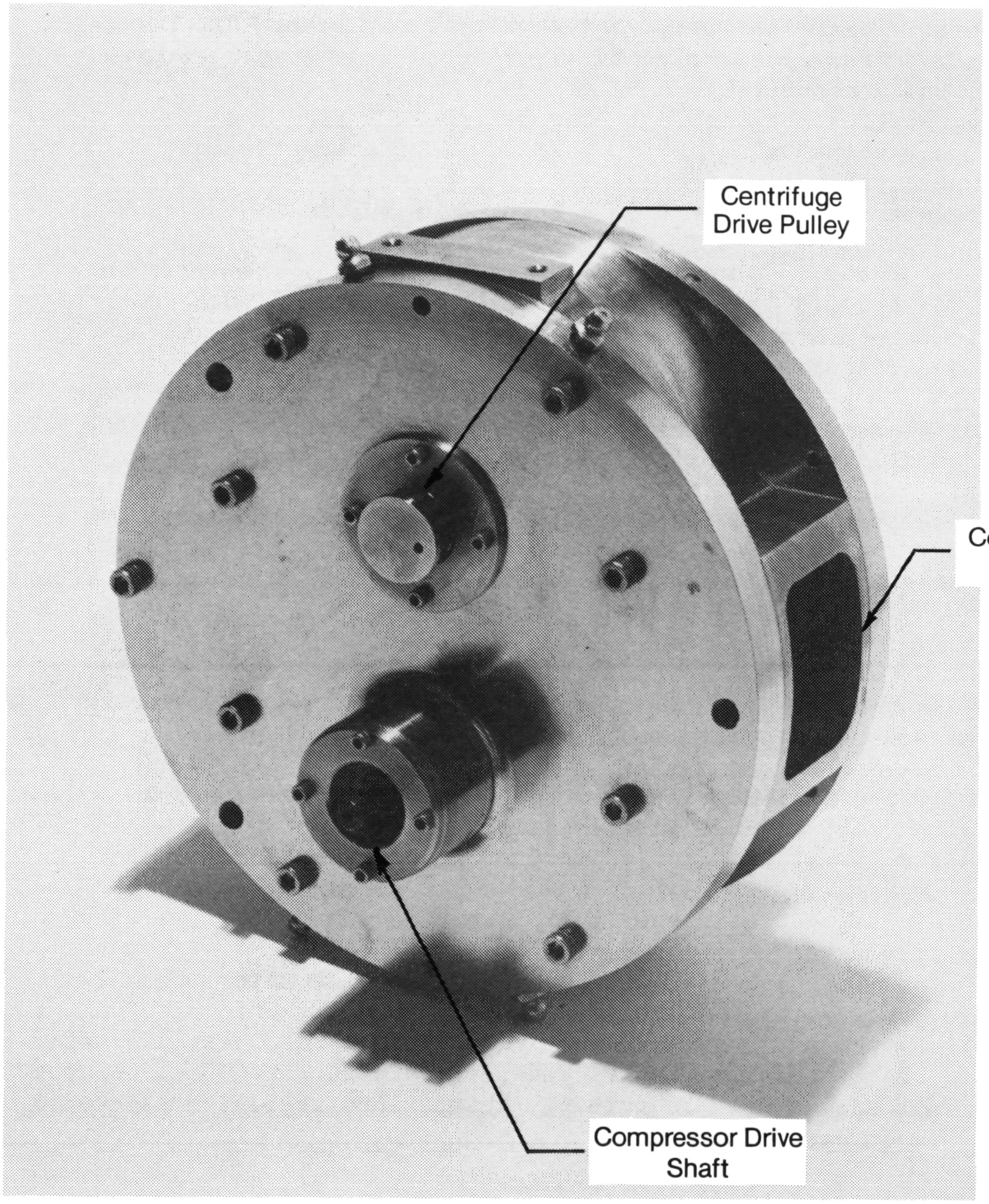

FIGURE 25 VCDS BASELINE ROTARY LOBE COMPRESSOR

Eight actuator override switches are provided which control the following test stand actuators: Compressor Drive Motor (M1), Tank, Water Pump Motor (M2), Wall Heater (H2), TSA Vacuum Valve (V11), Blower (B1), Evaporator Heater (H11/H12/H13) and Atmosphere Vent Valve (V12). In a normal operation position, the position for each actuator switch is in the "Auto" position. By switching it to either "On" or "Off" position, the automatic control for each actuator can be disabled and the actuator can be adjusted, operated or shut down manually, without turning off the main power supply of the test stand.

The temperature sensor reading (T3) from the evaporator, the water tank temperature (T8) and CTS chamber wall temperature (T5) are each controlled by a Temperature Control/Monitor (TeCM). The TeCM displays the present temperatures and status for all the three variables above.

The Compressor Chamber Monitor, which is located in the upper center portion of the front panel, consists of two pressure monitors, one selector switch and one temperature meter which displays the reading of the condenser temperature (T2), coolant temperature in the chamber (T6), coolant temperature out the chamber (T7) and the evaporator temperature (T11, T12). By changing the position of the switch, the temperature meter indicates the readings from any one of these four temperature sources.

The Compressor Drive Monitor is located in the upper left hand portion of the front panel. It monitors the compressor speed (S1) through a magnetic speed pick-up sensor and the magnetic coupling temperature (T4) by a thermocouple.

The Compressor Drive Monitor displays the compressor drive speed and magnetic coupling temperature. A shutdown signal is sent to the TSC if the compressor speed exceeds the low alarm setpoint for at least three seconds.

The Flow Monitor is located in the lower left-hand portion of the front panel. it contains a flow meter (F1) to monitor the water supply rate from the supply tank (TK6) to the CTC. The feed water is pumped by the water pump (PU1). A forward pressure regulator (PR1) with manual adjustment, which controls the bypass flow from the pump outlet to the inlet is used to adjust the water supply rate to the evaporator trays. The flow rate to the CTC evaporator trays can be increased simply by turning the pressure regulator clockwise or decreased in the opposite manner.

The CTS mechanical connections to lab facilities via an interface panel located behind the test stand are:

- Coolant In - an external coolant source which can provide chilled water at 70 lb/hr, 50 psig maximum is required to condense the water vapor discharged by the test article compressor.

- Coolant Out - coolant return line from the CTS.

- V/2 Atmosphere Vent - an electrically actuated two-way solenoid valve to allow the water supply tank to have access to ambient atmosphere.

- Deionized Water In - the port which is used to fill the CTS water supply tank (TK6) and also for water replenishment to compensate for long-term evaporation and vacuum purging losses during CTS operation.

- Test Support Accessory Vacuum port to the water supply tank (TK6) to simulate and maintain VCDS operating (subatmosphere) condition in the CTS. Design of the CTS requires continuous operation of the TSA vacuum purge during CTS operation.

Connection to a user-supplied Data Acquisition System (DAS) is provided on the test stand. Three terminal strips located behind the main control panel allow the DAS to monitor the following parameters.

- Evaporator temperature (T1)
- Condenser temperature (T2)
- Evaporator tray temperature (T3)
- Compressor speed (S1)
- Magnetic coupling temperature (T4)
- Coolant temperature (T6, T7)
- Chamber wall temperature (T5)
- Test stand elapsed time (Z1)

Unconditioned thermocouple signals are provided to a thermocouple (bimetallic) terminal strip. The remaining electrical signals are buffered DC, 0 to 5 V (or less) for analog and 0 or 5 V for digital. Table 11 summarizes the test instrumentation designed into the compressor test stand.

Fluids Pump Test Stand

The FPTS is a self-contained unit capable of permitting long-term VCDS fluids pump evaluation at simulated VCDS operating conditions. Figure 26 is a photograph of the test stand. The FPTS consists of four parallel process loops supplied by two pair of fluid tanks which simulate the VCDS waste feed, dual recycle loop and product water flows through the fluids pump. Figure 27 is a mechanical schematic of the FPTS. Table 12 summarizes the four operating modes of the FPTS. Table 13 summarizes the design range specifications for each parallel process loop.

From a systems packaging standpoint, the FPTS:

- Is a six-foot test stand bench with extra support frame reinforcement.

- Has an estimated maximum combined tank/fluid weight of 325 lb.[a]

- Has the fluid tanks located below to provide test stand low center of gravity.

(a) Assuming all tanks filled to capacity.

TABLE 11 CTS MINI-CHARACTERIZATION TEST INSTRUMENTATION

Type of Measurement	Type of Instrument	Measurement Location	Sensor Symbol	Expected Accuracy
Temperature	Thermocouple	Test Chamber Interior	T1 (T11, T12)	±4 F
	Thermocouple	Test Chamber Condenser	T2	±4 F
	Thermocouple	Magnetic Drive	T4	±4 F
Speed	Magnetic Speed Pickup	Magnetic Drive	S1	±10 rpm
Pressure	Gauge	Test Chamber Evaporator	PG1	±0.2 psig
	Gauge	Compressor Differential Pressure	PG2	±0.2 psid
Power	Wattmeter	Magnetic Drive Motor (M1)	-	±3 %

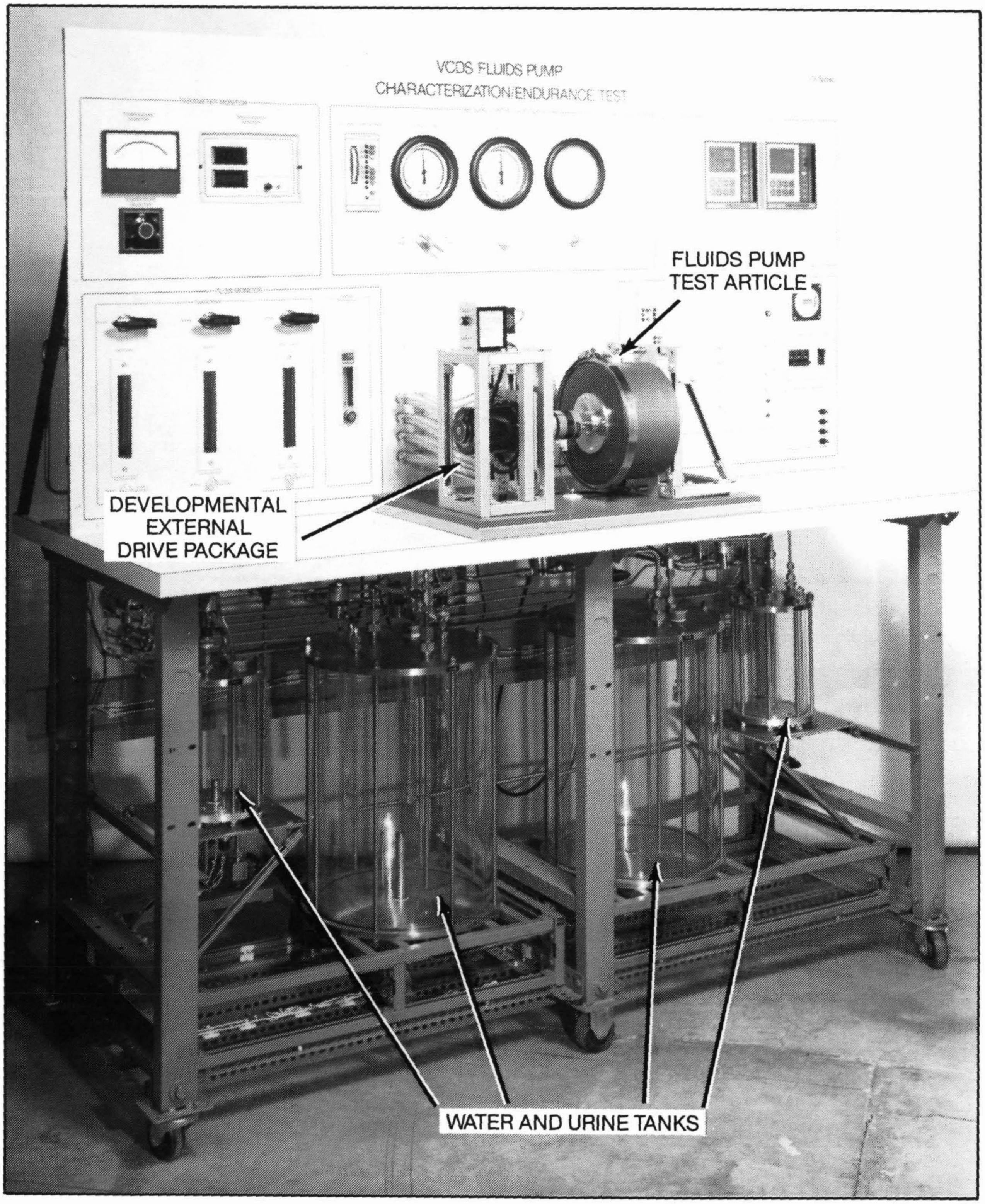

FIGURE 26 VCDS FLUIDS PUMP CHARACTERIZATION/ENDURANCE TEST STAND

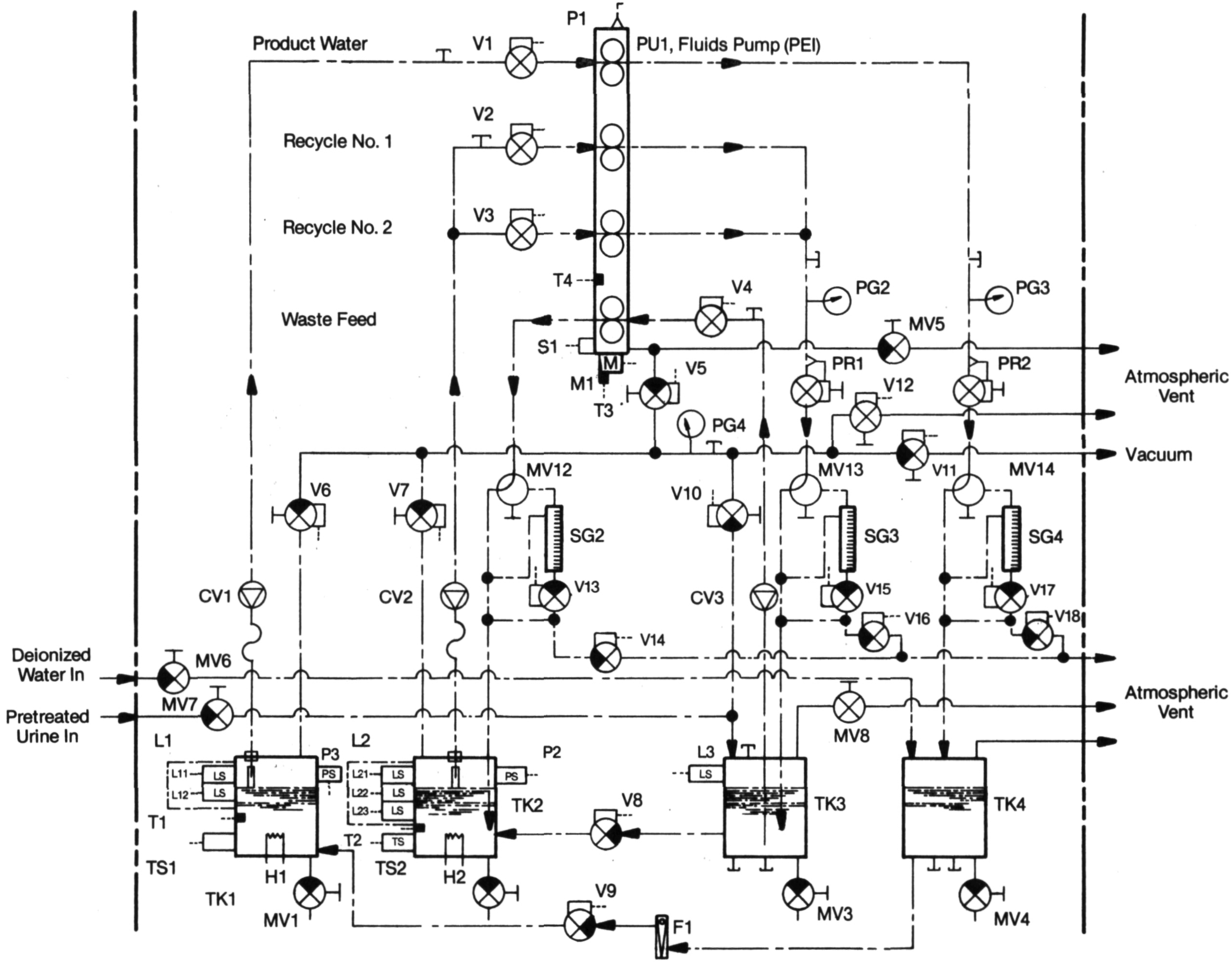

FIGURE 27 VCDS FLUIDS PUMP CHARACTERIZATION/ENDURANCE TEST STAND MECHANICAL SCHEMATIC WITH SENSORS

TABLE 12 FPTS OPERATING MODES AND UNPOWERED MODE DEFINITIONS

Mode (Code)	Definition
Shutdown (B)	The Fluids Pump is not pumping any water or urine. The current to the fluids pump motor (M1) is zero. The heaters (H1 and H2) are off, but the test stand is powered and all the sensors are working. The Shutdown mode is called for by: • Manual actuation • High water temperature (high TS1) in small water storage tank (TK1) • High urine temperature (high TS2) in small urine storage tank (TK2) • Low water level (low L12) in TK1 • High water level (high L11) in TK2 • High urine level (high L21, L22) in TK2 • Low urine level (low L23) in TK2 • High fluids pump casing pressure (high P1) • Low fluids pump speed (low S1) • Transition from Shutdown mode to Standby mode cannot be completed • Transition from Standby mode to Normal mode cannot be completed
Normal (A)	The FPTS is performing its function of pumping water and urine throughout the various fluid circuits by the peristaltic pump. The Normal mode is called for by: • Manual actuation • Auto restart after a power on
Standby (E)	The FPTS is ready to perform its function. Heaters (H1 and H2) are on and off per T1/TeCM and T2/TeCM control algorithm. The fluids isolation valves (V1, V2, V3 and V4) located upstream of the fluids pump are open. The Standby mode is called for by: • Manual actuation • Low water temperature (T1) • Low urine temperature (T2)
Unpowered (D)	No electrical power is applied to the test stand. All the actuators' positions cannot be verified. No fluid is processed. The Unpowered mode is called for by: • Manual actuation • Electrical power failure

TABLE 13 FPTS MECHANICAL SPECIFICATIONS

	Range	
	Nominal	Maximum
Flow, kg/hr (lb/hr)		
Waste Feed	6.80 (15.0)	19.6 (43.0)
Recycle No. 1	2.72 (6.0)	19.6 (43.0)
Recycle No. 2	2.72 (6.0)	19.6 (43.0)
Product Water	1.36 (3.0)	19.6 (43.0)
Inlet Pressure, kPa (psia)		
Waste Feed	94.4 (13.7)	170.2 (24.7)
Recycle No. 1	2.8 (0.40)	4.0 (0.58)
Recycle No. 2	2.8 (0.40)	4.0 (0.58)
Product Water	2.8 (0.40)	4.8 (0.70)
Discharge Pressure, kPa (psia)		
Waste Feed	2.8 (0.40)	4.0 (0.58)
Recycle No. 1	103.4 (15.0)	170.2 (24.7)
Recycle No. 2	103.4 (15.0)	170.2 (24.7)
Product Water	122.0 (17.7)	170.2 (24.7)
Temperature, K (F)		
Waste Feed	294 (70)	339 (150)
Recycle No. 1	305 (90)	339 (150)
Recycle No. 2	305 (90)	339 (150)
Product Water	305 (90)	339 (150)
Fluid Composition		
Waste Feed	Pretreated Urine[(a)]	
Recycle No. 1	Pretreated Urine[(b)]	
Recycle No. 2	Pretreated Urine[(b)]	
Product Water	Product Water	

(a) 0 to 5% solids concentration range during VCDS operation.
(b) 0 to 50% solids concentration range during VCDS operation.

- Has the fluid tank support structures standardized for FPTS and VCDS CTS.

Intrinsic safety features designed into the test stand include:

- All tank volumes sized twice the nominal tank design levels to prevent overfilling during fluid transfer from tank to tank.

- Flow measuring graduated sightglasses designed for one minute measurement time with two minutes fluid capacity and overfill bypass line to prevent sightglass flooding and breakage.

- Fluid Tank High and Low Liquid Level Fault Detection.

  - Detect Loss of Working Fluid
  - Prevent Immersion Heater Burnout
  - Prevent Fluid Tank Heat Damage

- Fluid Tank High Temperature Fault Detection Using Temperature Switches.

  - Prevent Immersion Heater Burnout
  - Prevent Fluid Tank Heat Damage
  - Provide High Temperature Relief

- Adjustable Pickup Snorkels in Fluid Supply Lines Provide Tank Level Adjustment and Control.

- Fluids Pump Low Speed Fault Detection.

  - Detect Progressive Failure of Fluids Pump Gearmotor Drive
  - Prevent Motor Burnout Due to Gearmotor Stalling or Seizure

- Vacuum/Vent Valving Arrangement (V11 and V12).

  - Vacuum Valve (V11) is Normally Closed to Isolate Vacuum Source from FPTS
  - Vent Valve (V12) is Normally Open to Vent FPTS to Ambient During Shutdown

- Fluids Pump Tube Failure Fault Detection.

  - Prevent Gross Spillage of Working Fluid Through Failed Tube
  - Shutdown FPTS Until Tube is Replaced

The FPTS tanks are a standardized design with a large and small tank version used. All tanks are constructed from Type 316 passivated stainless steel and clear acrylic plastic. The small tanks are sized to provide an equivalent fluid residence time to the large tanks, based upon the VCDS fluid flow rates simulated, namely:

- Large tank sizing provides a 76-minute fluid residence time, when filled to the five-gallon level, assuming a 35 lb/hr nominal flow rate (VCDS recycle loop flow rate).

- Small tank sizing provides the same residence time, when filled to the 0.38 gallon level, assuming a 5 lb/hr flow rate (150% of VCDS product water flow rate).

The two-phase flow (liquid and water vapor) characteristics of the VCDS are simulated by two fluid supply snorkels located within tanks TK1 and TK2, respectively. Each snorkel is set at the fluid level so that it suctions both liquid and vapor through the pump. The test stand fluid lines to the test article (fluids pump) inlet ports are provided with a capped line tee to permit initial line priming. Each fluid line also contains a low cracking pressure check valve (similar to those used on a VCDS) to maintain a column of working fluid to each pump inlet port.

Initial depressurization of test stand tanks TK1 and TK2 is required before starting the test stand for normal mode operation. Based upon extensive VCDS operating experience, the following tank pressures are nominally required in order to simulate the VCDS environment:

- 16 in Hg V at room temperature
- 15 in Hg V at 110 F
- 10 in Hg V at 150 F

An average tank pressure of 13 ± 3 in Hg V can be used to cover typical variations in test stand steady-state operation for long-term endurance testing.

The FPTS is designed to evaluate the following VCDS components as test articles:

- VCD2A fluids pump with external drive retrofit kit (Model B)
- Modified VCD2A fluids pump with internal harmonic gearmotor (Model C)
- Future improved fluids pumps with internal harmonic gearmotors

Figures 28 and 29 show the VCD2A baseline fluids pump.

The FPTS front panel consists of the following six main sections:

- TSC
- Heater Control/Monitor
- Pressure Control/Monitor
- Parameter Monitor
- Flow Monitor
- Test Article Mechanical Interface

The function of the TSC, located in the right hand portion of the front panel, is to control overall test stand operation, including main electrical power control, accumulation of operating time and automatic protection and shutdown control.

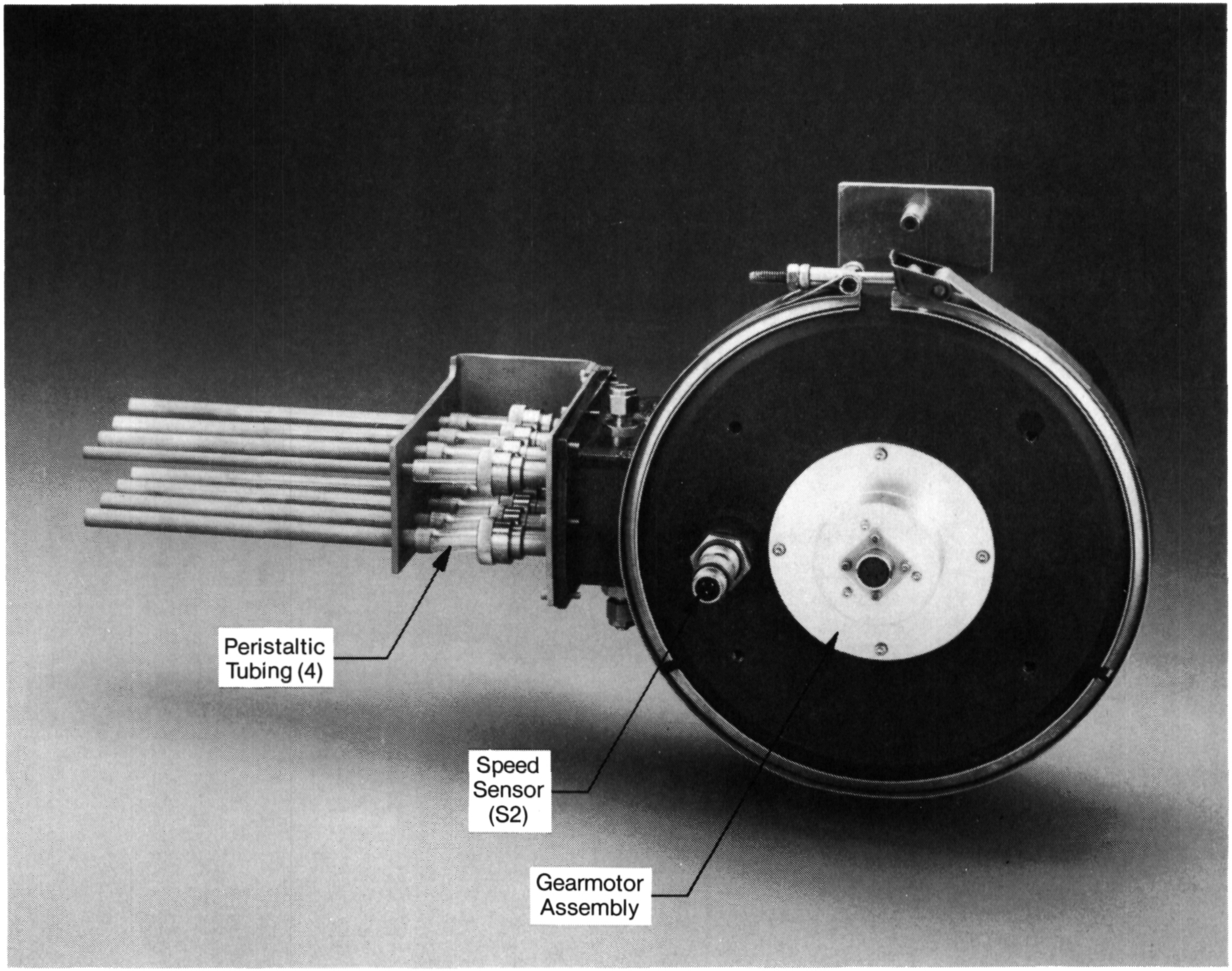

FIGURE 28 VCDS FLUIDS PUMP ASSEMBLY

FIGURE 29 VCDS FLUIDS PUMP (OPENED)

Shutdown signals are routed to a Shutdown Status Panel, which indicates which of the parameters initiated the shutdown. Alarm indications are provided for water level (L1) in tank (TK1), urine level (L2) in tank (TK2), water temperature (T1) in the water tank (TK1), fluids pump speed (S1), pump tubing leakage into the pump casing and the urine temperature (T2) in urine tank (TK2). A shutdown initiated by any of the six parameter monitors will result in a shutdown signal being sent to the Shutdown Status Panel. The shutdown signal will enable the appropriate indicator lamp and the status panel will then "latch" the lamp so that it remains lit in the event the alarm condition disappears. Additional shutdown signals initiated by other parameters will be received by the status panel, but will not immediately enable the indicator lamps due to the shutdown latching mechanism; thus, visibility for the parameter which initiated the shutdown is maintained. When the status panel reset switch is triggered, the latching mechanism is disabled and all shutdown signals received will then enable the appropriate indicator lamps.

In addition, the control/shutdown status panel provides indicator lamps for monitoring the cyclical operation of the four automated test stand control loops for fluid transfer and tank depressurization. Those status lamps indicate that the control loops are functioning properly. Failure of a lamp to light can, therefore, be used to troubleshoot a control problem.

Nine actuator override switches are provided which control the following test stand actuators: Fluids Pump Motor (M1), Water Heater (H1), Urine Heater (H2), Pump Casing Evacuation Valve (V5), Water Tank Evacuation Valve (V6), Urine Tank Evacuation Valve (V7), Urine Tank Evacuation Valve (V10), Vacuum Valve (V11) and Atmosphere Vent Valve (V12). In a normal operation position, the position for each actuator switch is in the "Auto" position. By switching it to either "On" or "Off" position, the automatic control for each actuator can be disabled and the actuator can be adjusted, operated or shut down manually, without turning off the main power supply of the test stand.

The temperature sensor reading (T1) from water tank (TK1) and the corresponding reading (T2) from urine tank (TK2) are each monitored by a microprocessor-controlled TeCM. The TeCM displays the present temperatures and status in both tanks.

The Pressure Control/Monitor (PCM), which is located in the top center portion of the front panel, consists of three pressure gauges, two pressure regulators, one pressure selector switch and the Fluid Pump casing Pressure Transducer Monitor (PM). The discharge pressure of the recycle flow is monitored by pressure gauge (PG2) and that of product water is monitored by pressure gauge (PG3).

The pressure selector switch permits the subatmospheric pressures from the water tank (TK1), urine tank (TK2), urine tank (TK3) and fluids pump casing to be displayed on pressure gauge (PG4). By changing the position of the switch, the pressure gauge indicates the pressure reading for any one of these sources by opening the appropriate solenoid valve which links these components to a common vacuum manifold and pressure gauge. A "Purge" position is located between each tank and pump casing, to permit the TSA vacuum to purge any residue fluid which is trapped in the manifold from the previous reading.

The backpressure regulators (PR1 and PR2) are used to regulate the discharge pressures of recycle flow and product water, respectively, to simulate the actual flow resistance within the VCDS. The fluids pump casing PM and pressure sensor P1 is used to monitor the fluids pump casing pressure and detect any leakage or breakage of peristaltic tubing in the pump casing.

The PM displays the present fluids pump casing pressure (P1) and status. The operator is alerted to the status of the pressure by indicator lights, which signal when the pressure has exceeded the Normal (green), Caution (yellow), Warning (flashing red) and Alarm (red) setpoint limits. During transient conditions, the indicator lights will register both the present pressure status, as well as the status of the highest pressure reached and maintained for at least three seconds during the transient.

If there is a sudden change in pressure, such as the external leakage of pump casing or breakage of fluids pump tubing, the automatic shutdown protection of the PM will send a shutdown signal to the TSC if the pressure exceeds the alarm setpoint for at least three seconds. The time delay required by the fault detection eliminates false shutdowns caused by noise.

The Parameter Monitor, located in the upper right hand portion of the front panel, contains a Temperature Monitor, a Temperature Selector and a Speed/Power Monitor (SPM). By changing the position of the Temperature Selector, it can monitor the temperature of the pump gearmotor casing (T3) or that of the fluids pump casing (T4). The function of the SPM is to monitor the input speed (rpm) and power (drive current) to the gearmotor. The speed of the gear motor can be adjusted by changing the actuator override switch for the fluid pump motor in the Actuator Override Panel to "On" from "Auto," then adjust the speed adjustment knob on the external drive package.

The Flow Monitor, located in the lower left corner of the print panel, monitors the flow rates of the waste feed, recycle flow and product water fluid circulation loops by three graduated sightglasses (SG1, SG2 and SG3), respectively. The water transfer flow rate from the ambient water tank (TK4) to the vacuum water tank (TK1) is preset and monitored through the flow meter (F1). The procedure to measure the flow rate for the waste feed, product water and recycle flow is as follows:

1. During normal operation, the manual three-way valves (MV12, MV13 or MV14), located at the top of the sightglasses (SG2, SG3 or SG4) will be in the "Bypass" position.

2. Similarly, the dial switches for the drain valves (V13/V14, V15/V16 or V17/V18), located at the bottom of the sightglasses will be in the "Bypass" position.

3. Turn the drain valve (V13,V14, V15/V16 or V17/V18) dial switch to "Flow Measure."

4. Turn the manual three-way valve (MV12, MV13 or MV14) to "Flow Measure." Immediately start a hand-held stopwatch (part of required TSAs) the timer and count the time to fill the sightglasses.

5. Repeat Steps 2 and 1 in that order to drain the respective sightglass and reset it for normal operation.

6. Convert the time of filling each sightglass to the equivalent flow rate. Flow rate is computed as follows:

$$\dot{m} = 7.933\ V/t, \text{ where}$$

$\dot{m}$ = mass flow rate, lb/hr
V = fluid volume collected in sightglass, cc
t = time to collect fluid volume, sec

Connection to a user-supplied DAS is provided on the test stand. Two terminal strips located behind the main control panel allow the DAS to monitor the following parameters:

- Water tank temperature (T12)
- Urine tank temperature (T22)
- Fluids pump gearmotor temperature (T32)
- Fluids pump casing temperature (T42)
- Fluids pump casing pressure (P1)
- Test stand elapsed time (Z1)
- Product water discharge pressure (P6)
- Recycle loop discharge pressure (P5)
- Vacuum manifold pressure (P4)
- Fluids pump speed (S1)
- Fluids pump drive current (I1)

Unconditioned thermocouple signals are provided to a thermocouple (bimetallic) terminal strip. The remaining electrical signals are buffered DC, 0 to 5V (or less) for analog and 0 or 5V for digital. Table 14 summarizes the test instrumentation designed into the fluids pump test stand.

Improved VCDS Components Development

A follow-on component enhancement and testing effort was successfully completed which emphasized the improvement, upgrading and testing of key VCDS components. Hardware reliability, long life and maintainability were stressed with a goal to advance the state-of-the-art and identify component and subsystem configurations for future VCDS Technology Demonstrator and flight hardware.

Specific goals of this components development effort were:

- Develop improved subsystem components emphasizing reliability, long life and maintainability.

- Upgrade and improve the VCDS centrifuge and compressor bearings.

TABLE 14 FPTS MINI-CHARACTERIZATION TEST INSTRUMENTATION

Type of Measurement	Type of Instrument	Measurement Location	Sensor Symbol	Expected Accuracy
Temperature	Thermocouple	Water Supply Tank (TK1)	T1	±4 F
	Thermocouple	Urine Supply Tank (TK2)	T2	±4 F
	Thermocouple	Gearmotor (M1)	T3	±4 F
	Thermocouple	Pump Casing (PU1)	T4	±4 F
Speed	Magnetic Speed Pickup	Fluids Pump (PU1)	S1	±1 rpm
Pressure	Gauge	Pump Recycle Discharge (PU1)	PG2	±0.2 psig
	Gauge	Pump Product Water Discharge (PU1)	Pg3	10.2 psig
	Transducer	Pump Casing (PU1)	P1	±0.2 psig
Flowrate	Graduated Sightglass + Stopwatch	Pump Discharge Lines (3)	SG1 SG2 SG3	±1 cc ±1 sec
Power	Wattmeter	Gearmotor (M1)	-	±3 %

- Increase life and simplify the design of the magnetic drive assembly by eliminating the life-limiting thrust bearing within the preprototype version.

- Increase water production rate while reducing specific energy through optimized component design and integration.

- Integrate and test a higher capacity, high efficiency compressor within the VCDS.

- Develop and test an improved fluids pump drive assembly which provides long life.

Two design constraints were defined for all new hardware:

- Hardware must be sized for simple retrofit and operation within the advanced preprototype VCDS.

- Hardware must be constructed from materials, both metallic and nonmetallic, which promote long-life corrosion-free service within a pretreated urine wastewater environment.

The above program goals were realized through the development of the following improved VCDS components:

- Improved centrifuge bearings fabricated with stellite alloy balls and races, incorporating a self-lubricating graphite ball retainer and integral bearing seal for long-life, corrosion-free service.

- A lightweight L/D = 1 rotary lobe compressor which provides three times the water vapor flow capacity, yet achieves a 6% weight reduction over the original VCDS compressor.

- A radial magnetic coupling assembly integrated directly into the rotary lobe compressor, eliminating misalignments and the need for life-limiting thrust bearings. The improved magnetic coupling uses rare earth permanent magnet technology which is energy and volume efficient.

- A long-life, efficient gearmotor drive assembly for the fluids pump, based upon harmonic drive technology, which demonstrated over 2,000 hours of operating life and continues to function.

All hardware development was able to take advantage of test data resulting from the VCD2A parametric test program conducted during 1985. This test program demonstrated the capability of VCDS hardware to successfully process wastewater for over a 90-day operating period. Hardware problems, identified during testing, became the previously-mentioned goals for improved component development as a follow-on activity.

Upon completion of hardware design and fabrication, installation of these improved components into the existing VCD subsystem resulted in the conversion of the advanced preprototype unit, designated VCD2A, into the improved VCDS, designated as the VCD2B. A follow-on limited test program for the VCD2B, conducted during 1986, successfully demonstrated over 90 days of hardware operation while processing wastewater without a hardware failure. Table 15 summarizes the hardware improvements which resulted in the transformation of VCD2A into VCD2B. The last row in Table 15 represents the final VCD2B configuration.

Detailed test results for the VCD2A and VCD2B test programs may be found elsewhere in this report. The following report sections summarize the primary features of the improved VCDS components.

Improved Centrifuge and Compressor Bearings

The improved centrifuge bearings development effort called for the design, fabrication and delivery of improved centrifuge bearings in three different bearing materials combinations for direct evaluation within the VCD2A or VCD2B subsystem configurations.

Previous VCDS testing with standard, low cost, conventional commercially-available bearings revealed that these bearings were susceptible to corrosion from the presence of the pretreated urine within the distillation unit. As a consequence, Life Systems determined the need for identifying corrosion-resistant materials and new bearing geometries to improve centrifuge bearing life beyond 10,000 hours.

The development effort involved working closely with an aerospace-quality bearing vendor to define improved bearing materials and geometries for long-life VCDS centrifuge service. The objective was to determine if the following bearing design features would maximize bearing life:

- Incorporation of a single integral nonmetallic seal in all centrifuge bearings to prevent wastewater contamination of the bearing.
- Use of Type 440C stainless steel and other exotic alloys to resist corrosion and provide adequate material hardness for a bearings application.
- Evaluate the use of virgin Teflon and graphite-impregnated materials to provide bearing self-lubrication without the need for grease lubricants.

An additional design criterion for the improved centrifuge bearings was that they be directly retrofitted into the VCD2A or VCD2B distillation unit without requiring centrifuge modifications.

The end products for this task were three pair of compressor-end and hub-end centrifuge bearings constructed from various bearing grade, corrosion-resistant materials for direct installation in the VCDS centrifuge.

TABLE 15 VCDS CONFIGURATION DEFINITION

VCDS Configuration	Centrifuge Bearings[a] Compressor End	Centrifuge Bearings[a] Hub End	Demister	Compressor/ Timing Gears	Centrifuge Drive Belts
VCD2A	52100S/52100S/Rulon (w/o seal)	440C/440C/Rulon (w/o seal)	VCD2A Baseline	• VCD2A Baseline • Vespel/ 316 S.S (0.375 width)	• EPR O-Ring • Neoprene
VCD2A/440C Bearings	440C/440C/Rulon (w/seal)	440C/440C/Rulon (w/seal)	VCD2A Baseline	• VCD2A Baseline • Vespel/ 316 S.S (0.375 width)	• EPR O-Ring • Neoprene
VCD2B (1986)	Stellite/Stellite/ Torlon (w/seal)	Stellite/Stellite/ Torlon (w/seal)	VCD2A Baseline	• L/D = 1[d] • Vespel/ 316 S.S (0.750 width)	• EPR O-Ring • Neoprene
	440C/440C/ Torlon (w/seal)	Stellite/440C/ Torlon (w/seal)	VCD2A Baseline	• L/D = 1 • Vespel/ 316 S.S (0.750 width)	• EPR O-Ring • Neoprene

continued-

(a) Bearing materials of construction designated races/balls/retainer.

Table 15 - continued

		Fluids Pump		
VCDS Configuration	Magnetic Coupling	Fluids Pump	Fluids Pump Speed Control	Recycle/Filter Tank
VCD2A	VCD2A Baseline (Axial)	VCD2A Baseline	VCD2A Fixed Speed at 15.7 rpm	• VCD2 Baseline • Small Plastic Tank
VCD2A/440C Bearings	VCD2A Baseline (Axial)	VCD2A Baseline	VCD2A/External Variable Speed Pump Gearmotor	• Small Plastic Tank • Alternate Large Tank
VCD2B (1986)	Improved[a] (Radial)	VCD2A Baseline	VCD2A/Model "B" Retrofit Kit[b]	• Alternate Large Tank • Small Plastic Tank
	Improved[a] (Radial)	VCD2A Baseline	VCD2A/Model "B" Retrofit Kit[b]	• Alternate Large Tank • Small Plastic Tank

(a) Requires installation of L/D = 1 compressor and compressor integration kit.
(b) Includes a 100 to 1 reduction harmonic drive, externally integrated to fluids pump with TSA motor (variable speed), and plate added to roller to ensure total tube support.

In a parallel effort, similar bearings were designed, fabricated and delivered for installation within the improved VCDS compressor and idler pulley assembly of the centrifuge drive train.

The design features incorporated into the improved compressor/idler pulley bearings include:

- Similar dimensions to existing compressor and idler/pulley bearings to permit retrofitting.
- A single integral seal to prevent wastewater contamination.
- A bearing configuration (compressor and idler pulley) which incorporates a standard grease lubricated ball retainer.
- A bearing configuration (compressor and idler pulley) which incorporates a similar ball retainer which require no grease lubricants.

Installation and evaluation of either the grease-lubricated or self-lubricated bearings into the VCD2B were conducted as part of the VCD2B test program.

The end products for this task were the fabrication of 16 compressor bearings and two idler pulley bearings in the grease-lubricated configuration, and eight compressor bearings and two idler pulley bearings in the self-lubricated configuration.

L/D = 1 Compressor and Compressor Integration Kit

A major component development effort was undertaken to design and test an improved VCDS compressor and its associated integration hardware. A compressor with a lobe length-to-diameter ratio of one (L/D = 1) was selected to minimize compressor slip speed losses.

The primary objective for selecting an L/D = 1 compressor with 4 x 4-in lobes was to permit a 50% reduction in compressor speed while maintaining the throughput capacity of the existing VCD2A L/D = 0.62 compressor. A reduction in compressor speed from 3,400 rpm to 1,700 rpm required the resizing of drive pulleys within the distillation unit to maintain the 289 rpm centrifuge speed. This is necessary to maintain waste fluid film formation and flow within the evaporator section of the centrifuge.

The following list summarizes the key design features of the L/D = 1 compressor:

- 4 x 4 inch lobe size to increase pumping capacity and reduce compressor speed.
- Titanium lobes keyed and press-fitted onto stainless steel shafts to minimize weight and maximize corrosion resistance (the 1.72 x 4 compressor used commercial cast iron lobes which required a protective Teflon coating).

- Titanium housing parts to minimize weight.

- Permit installation of the radial magnetic coupling directly to the compressor casing to optimize alignment.

- Utilize characteristic lobe contours identical to the existing VCD2A compressor lobes to minimize development risk.

The successful completion of the VCD2A Parametric Test Program resulted in the subsystem operating for 1,935 hours in the Normal mode processing both water and pretreated urine at condenser temperatures ranging from 90 to 162 F. Operation of the existing VCD2A compressor timing gears revealed several areas for design improvement.

A detailed stress analysis of the compressor timing gears, combined observations made during VCD2A testing, resulted in the following gear improvements:

- The gear face width was doubled to reduce gear tooth stresses by 50%, increasing gear fatigue life.

- A stainless steel hub incorporated into the vespel driven gear to eliminate keyway stress concentrations.

- A wave spring/retaining ring was incorporated to lock driven gear to compressor shaft which provides a self-energizing locking method.

- The stainless steel driver gear was designed slightly wider than the driven gear to prevent loading of nonmetallic gear teeth edges and chipping.

The improved timing gear set, evaluated as part of the L/D = 1 compressor during VCD2B testing, successfully operated for over 90 days without failure. Post-test examination of the gears revealed that all design problems identified previously were successfully resolved.

A compressor integration kit was added to the distillation unit to permit installation of the L/D = 1 compressor. Kit parts included are:

- Outer shell spool casing
- Extended centrifuge drum pulley
- 3,200 rpm/1,600 rpm idler pulleys
- Upgraded still end plate
- 3,200 rpm/1,600 rpm timing idler pulleys
- Additional V-band clamp for outer shell

The conversion kit consisted of hardware to extend the length of the distillation outer shell to provide more internal volume for the larger compressor. The centrifuge drive pulley, steam detector shell, belt/pulley drive train and compressor mounts also required adapters or modified replacement parts to permit compressor changeover. The integration hardware emphasized the capability to return the VCDS back to its original VCD2A configuration for smaller baseline compressor testing. Modifications to the existing VCDS distillation unit end plate (enlargement of the existing magnetic drive feed through bushing) were required to directly mount the improved magnetic coupling onto the compressor end plate.

Other design goals of the compressor integration kit which were successfully achieved were the following:

- Two L/D = 1 (4 x 4) compressor lobes are used to increase the capacity of the compressor. As a result, width of the centrifuge drive pulley is extended 2.22 inch longer to accommodate the longer compressor lobes. The overall length of distillation unit increased by less than one inch because the design of radial magnetic coupling was more compact, and directly mounted to the compressor casing.

- The steam passages within the centrifuge drive pulley were sized to maintain an equivalent flow velocity through the VCD2B that is not greater than that of the VCD2A. Therefore, there will be less backpressure generated between the compressor and the tank pulley in VCD2B; however, the total flow rate of steam vapor is much higher for VCD2B.

Initial test results from the VCD2A test program indicate that centrifuge belt slip could occur. A review of the O-ring drive design was conducted and found that the existing O-ring belt drive was acceptable for operation at temperatures below 110 F. At above normal VCDS operating temperature, high stress relaxation in the O-ring belt in which the belt loses tension, would cause slippage on the drive pulley. Engineering analysis indicated that a larger drive belt would provide additional belt tension such that the long-term presence of temperatures above 110 F and humidity during the elevated temperature portion of parametric testing would not cause excessive stress relaxation within the drive belt. The solution to the problem, based upon the engineering analysis performed, was to replace the existing O-ring belt with one having a 29% larger diameter. Increasing the O-ring cross-sectional area reduced working stresses, so that a higher belt tension could be carried by the O-ring drive belt without shortening belt life or producing belt slippage due to stress relaxation. Increasing the O-ring drive belt cross-sectional area by 72% increased the belt stress factor of safety by 500%, to prevent belt slippage due to stress relaxation during VCDS operation. The larger cross-sectional diameter O-ring was incorporated into the design of the L/D = 1 compressor integration kit design which required a new centrifuge drive pulley to accommodate the larger compressor.

Examination of the drive timing belt after VCD2A testing indicated that the used timing belt lost tensile strength. An analysis of the weakened timing belt revealed that the fiberglass cords used to reinforce the neoprene belt carcass were made brittle by water vapor permeation. During normal VCDS operation, the timing belt will be exposed to saturated water vapor at subatmospheric conditions.

The corrective action taken was to specify a kevlar-reinforced neoprene timing belt. The kevlar cords are not affected by water vapor and provide superior bending (flexure) fatigue life when compared to more conventional stainless steel reinforced timing belts. The kevlar/neoprene belt construction is considered to be state-of-the-art in timing belt technology.

Testing of the improved timing belt within the VCD2B verified the solution to this problem.

Radial Magnetic Drive

The objective of the radial magnetic coupling design was to eliminate the axial thrust load in the existing axial magnetic coupling of the VCD2A. Note, that the use of off-the-shelf "pancake" magnets within the VCD2A coupling resulted in an axial coupling design which requires small button thrust bearings to react axial magnetic forces on either side of the vacuum shell separator plate. The improved design also utilized more efficient magnetic materials to reduce weight and volume.

This drive coupling concept utilizes a radial magnet geometry in which a "male" magnet coupling half drives a "female" driven coupling half via radial magnetic lines of force. The advantages of this design geometry are no axial forces due to magnetic lines of force which eliminates the need for thrust bearings. The female hub is connected to the distillation unit motor and the male hub is connected to the drive rotor of the compressor. The motor and the framing spacer with the female hub are mounted to the compressor end plate by six fasteners. This subassembly is designed to satisfy Orbital Replacement Component (ORC) requirements for subsystem maintenance. To assure all the mounting faces and rotating components are lined up, all the parts are either guided or piloted in this design. For example, the compressor hub is piloted into the compressor end plate, and is concentric to the drive rotor center line, the support framing spacer which connects the drive motor to the compressor is guided into the inside diameter of compressor hub. The inside diameter of the separator casing between male and female magnetic hubs is also piloted to the compressor end plate to maintain concentricity between the magnetic hubs and separator.

All the materials of construction in the magnetic coupling are corrosion resistant, and compatible with a VCDS operating environment. The separator casing between the male and female magnetic hubs is made of stainless steel.

Two improved magnetic coupling assemblies (SN01 and SN02 units) and associated end plates and adapter hardware were fabricated to permit installation into the VCDS and VCDS CTS. Both coupling assemblies have performed for over 90 days as part of the VCD2B test effort without failure.

Improved Fluids Pump Drive

Previous VCDS testing during 1980 and 1983 had revealed that the original pump drive required lubrication after about 600 hours of operation. The original (preprototype VCDS) pump drive was a commercially-available four-stage planetary gearbox designed for only 500 hours of service, according to the vendor catalog specifications.

To rectify this situation, the life-limiting gearbox was replaced with a device known as a "harmonic" drive. The term "harmonic drive" is the name given to a new family of machine systems which use the controlled elastic deflection of one or more parts for the transmission, conversion, or change of mechanical motion. The basic mechanism of harmonic drive has the broad multipurpose capabilities of the simple lever and has proved itself adaptable to such diverse forms of mechanical systems as rotary to rotary motion transmissions, rotary to linear motion converters, linear to linear transmissions, and rotary pumps and valves. Harmonic drives have been successfully used in the NASA Lunar Rover drive, Skylab gyroscopes and various missile fin actuator mechanisms.

Until now, nearly all mechanical systems have been based upon the well known law of "rigid body mechanics," and considerable effort has been devoted to reducing the spring flexure of machine parts to an absolute minimum. Rotating elements have been assumed to remain rigid and rotate circularly about six axes. Harmonic drive technology is a radical departure from traditional mechanics and requires entry into a new realm of nonrigid mechanics, or elastokinesis--a new field of elastic body dynamics.

Within a typical harmonic drive is a component called the wave generator which is elliptoidal in shape and surrounded by a ball bearing. A flexspline containing external teeth and a circular spline containing internal teeth come into mesh resulting in a two-tooth difference equal to the number of lobes of the wave generator. As the wave generator is turned, the flexspline is progressively deflected to follow the rotating elliptoidal shape. The flexspline and circular spline are held in engagement at the major axis of the wave generator and are fully disengaged and clearing at the minor axis. Spline teeth come into contact with an almost pure radial motion and have essentially zero sliding velocity, even at high input speeds. Tooth friction losses and tooth wear are, thus, very low. Because of low friction losses, high mechanical efficiencies can be obtained, which are particularly outstanding at high ratios. In addition, low friction results in long operating life for the drive.

As a result, harmonic drive "gearboxes" feature a novel gear meshing design in which a flexible spline harmonically oscillates into and out of gear mesh; thus, eliminating the conventional sliding/rolling contact between gear teeth and associated gear tooth wear. The harmonic gear drive, therefore, provides the capability for minimum gear tooth backlash, minimum gear tooth wear and maximum drive life by virtue of the novel gear meshing arrangement.

For VCD2B testing and evaluation, a commercially-available harmonic drive was selected with a 100 to 1 speed reduction and coupled to an existing variable-speed AC brushless motor. This motor had been previously used as a test support accessory during the VCD2A testing effort to provide variable fluids pump speeds. The entire drive assembly was externally retrofitted to the VCDS fluids pump and connected to the pump eccentric roller by a drive shaft.

This motor included a stand-alone motor speed controller box which did not impact motor control integration into the Model 140A C/M I. The external motor controller, however, was manually adjustable and was not intended to be automatically controlled by the C/M I, other than automatic shutdown which was provided with the existing test setup for parametric testing.

The externally-refitted harmonic drive performed without a problem during the 90-day VCD2B test program.

CONCLUSION

Regenerative life support systems are required for long-term manned presence in Space. Candidate subsystems must be developed and extensively tested to ensure their readiness for Space Station application. Recent parametric testing and incorporation of hardware improvements of an advanced preprototype VCDS advances phase change water recovery technology toward that goal. The VCDS was designed to incorporate the operational concepts needed for projected Space Station application. Additional development work in the form of specific component enhancements and follow-on parametric testing to characterize and optimize the process have been completed. Results obtained from these ongoing efforts will be incorporated into a future VCDS Technology Demonstrator unit. Based upon the results from the VCDS parametric test program, the following conclusions were reached:

1. A VCDS is a viable candidate for a Phase Change Water Recovery Subsystem aboard a manned Space Station.

2. The VCDS water quality was found to be relatively insensitive to operating temperature.

3. The VCDS water production rate is dependent upon wastewater recycle flow rates, and has been shown that it can be optimized by adjusting the fluids pump speed to a lower value, which increases pump life. In particular, over 9,000-hour equivalent pump tubing life was demonstrated.

4. The VCDS rotating evaporator/condenser has successfully processed wastewater for over 10,000 hours in a preprototype and an advanced preprototype VCDS without fouling or degradation and is, therefore, superior to the evaporator designs of alternative phase change water recovery techniques.

5. Recent testing of a VCD2B configuration has demonstrated a dramatic 300% increase in water production rate while maintaining a specific energy rating of less than 77.3 W-h/kg (35 W-hr/lb). This improvement requires only a 7% increase in distillation unit packaging.

6. Because of the 300% improvement in water production rate, only one VCDS per Space Station module would be required to process both urine and washwater for a six-person crew. This permits a substantial reduction in the weight, power, volume and complexity of a Space Station water reclamation system, when compared to the alternative phase change water recovery techniques currently being considered.

RECOMMENDATIONS

The following summarizes recommendations for follow-on VCDS efforts, based upon results obtained from extensive subsystem testing conducted between late 1984 through 1986. During that time frame the VCD2A and VCD2B configurations were both evaluated. Recommendations are arranged in the following major tasks:

1. VCD2B to VCDS, Advanced Unit (VCD III) Conversion - It is recommended that the existing VCD2B be converted to the VCD III (recently built for NASA Marshall Space Flight Center). The conversion would provide NASA JSC with the following superior features:

   - Most current C/M I and applications software technology for ECLS Subsystems

   - Permits a VCDS to act as a pathfinder for evaluating generic signal conditioning

   - Permits C/M I compatibility with a Performance Display Unit which simulates the Space Station Module main control/display

   - Provides maximum flexibility for utilizing a VCDS in expert systems development and pathfinding

2. VCDS Follow-on Testing - The following follow-on testing is recommended:

   - Further analyses and testing to optimize purge control.

   - Further analyses of test results and follow-on testing are recommended to determine and quantify limiting heat transfer resistances from condenser to evaporator so that hardware modifications can be defined to further decrease specific energy and/or compressor speed (for increased life).

   - Detailed compressor characterization and endurance tests using Compressor Test Stand to allow for compressor speed optimization and capacity matching with the thermal "size" of the distillation unit.

- Added tests using various mixture ratios of urine and hygiene water (and soaps) be conducted with special emphasis on pretreat compatibility and solids precipitation.

- Detailed fluids pump characterization and endurance tests be run using FPTS to evaluate tubing life and pump characteristics.

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