NASA/TM—1998–208539

Final Report on Life Testing of the Vapor Compression Distillation/Urine Processing Assembly (VCD/UPA) at the Marshall Space Flight Center (1993 to 1997)

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August 1998

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ABBREVIATIONS, ACRONYMS, AND DEFINITIONS

>	leads to (as in “T1 high alarm > shutdown”) greater than (as in “K1 > 250 μmho/cm”)
<	less than
A	amperes of current
alarm (v.)	Signifies that a sensor has entered an intolerable operating range and the VCD/UPA will begin a transition to the shutdown mode automatically.
CHeCS	Crew Health Care System
CL1	Sensor that provides information on the solids content of the brine.
Control/Monitor Instrumentation	The electronic instrumentation that monitors and controls the subsystem. It consists of a signal conditioner, a controller, and a motor speed controller.
DA	distillation assembly—The distillation assembly is a highly integrated mechanical assembly that enables the evaporation of water from a flowing wastewater stream, provides condensation of water vapor to form product water, and provides liquid/vapor separation in microgravity. The DA consists of the DU, motor and drive components, and ancillary components such as a heat exchanger, sensors, and connectors.
dc	direct current
DU	distillation unit—The centrifuge component of the DA, including the compressor.
ECLS	Environmental Control and Life Support
ECLSS	Environmental Control and Life Support System
EEF	End-use Equipment Facility—The room containing exercise equipment, washing facilities, and a urinal for generating wastewater for processing.
EPROM	Erasable Programmable Read Only Memory (computer firmware)
FCA	fluids control assembly—The fluids control assembly manages and directs the flows of waste feed, waste recycle, and product water.
FPA	fluids pump assembly—Pumping of wastewater to the distillation assembly and pumping of both concentrated wastewater and product water from the distillation assembly is accomplished by a multipath, single motor fluids pump assembly.
Harmonic Drive	the manufacturer of the fluids pump and purge pump drive mechanisms
hr	hour(s)
in.	inches
ISS	*International Space Station*
ISS UPA	VCD that will be used on board the USOS of the *ISS*

K1	VCD–5 product water conductivity sensor
L1	liquid level sensor in the distillation unit
LSI	Life Systems, Inc.—manufacturer of the VCD
μm	micrometer or micron
μmho/cm	measurement of water conductivity
min	minute(s)
mm	millimeters
N/A	not available
Normal	see *Operating Modes*
Norprene®	Material of the peristaltic pump tubing, a registered trademark of the Norton Performance Plastics Corporation.
Operating Modes	The four operating states of the VCD/UPA are: *Normal*—The VCD/UPA recovers water from wastewater. *Standby*—The VCD/UPA is waiting for sufficient pretreated urine and urinal flush water to accumulate in the wastewater storage assembly before automatically transitioning to the *normal* mode. *Unpowered*—The VCD/UPA is unpowered and all sensors and actuators are deenergized. *Shutdown*—The VCD/UPA is not receiving or recovering water, all actuators are deenergized and all sensors are functioning.
PACRATS	Payloads and Components Real-time Automated Test System—data acquisition system used during the WRT Stage 10.
PCA	pressure control assembly—The primary function of this component is to periodically purge the distillation assembly of noncondensable gases that enter as dissolved or free gases with the wastewater feed. As noncondensable gases increase in the distillation assembly condenser, the pressure will increase. The pressure control assembly monitors this pressure increase and enables the purge pump assembly when a purge is, required. The purge pump assembly pumps the noncondensable gas with steam to pressures above ambient. From there, the noncondensable gas and steam condensate pass through a membrane gas/water separator where product water condensate is recovered from the noncondensable gas and routed back into the product water stream. The noncondensable gases are released to the atmosphere.
PDU	performance display unit—An element of the test support accessories that simulates the higher level command interface to the ECLSS subsystem. It provides an interface to enable monitoring of the hardware performance and high level commands.
POST	Predevelopment Operations Systems Test
Power Distribution and Control Assembly	An element of the test support accessories that provides the interface between the facility power and the subsystem.

PPA	purge pump assembly—The purge pump assembly provides the pumping necessary to purge noncondensable gases from the distillation assembly condenser to atmosphere.
Q1	sensor measuring the bellows position in the wastewater supply tank
RFTA	recycle filter tank assembly—The accumulation and filtering of concentrated wastewater brine is performed in this assembly. In addition, it provides a containment vessel for storing and transporting the concentrated brine during flight tank resupply.
rpm	revolutions per minute
S4	still drum speed sensor
SCATS	Systems and Components Automated Test System—computerized data collection and monitoring system.
Shutdown	see *Operating Modes*
Standby	see *Operating Modes*
Test Support Accessories	devices that simulate the interfaces to the VCD
TIC	total inorganic carbon
TOC	total organic carbon
Unpowered	see *Operating Modes*
UP	urine processor
UPA	urine processing assembly
USOS	United States on-orbit segment of the *ISS*
VCD/UPA	vapor compression distillation/UPA
VCD–5	one of the VCD's used for life testing (sometimes referred to as the VCD–V)
VCD–5A	one of the VCD's used for life testing (sometimes referred to as the VCD–VA)
Vdc	Volts, direct current
Vespel®	the composition of one of the compressor gears, to provide lubrication, a registered trademark of the DuPont Company
warning (v.)	signifies that a sensor has entered a range that indicates an unusual operating condition that may soon lead to an alarm condition
WP	water processor
WRT	water recovery test
WSA	wastewater storage assembly—Storage of wastewater is performed by this component. By monitoring the quantity of wastewater in the storage tank, this assembly will initiate automatic startups and shutdowns of the VCD.

TECHNICAL MEMORANDUM

FINAL REPORT ON LIFE TESTING OF THE VAPOR COMPRESSION DISTILLATION/URINE PROCESSING ASSEMBLY (VCD/UPA) AT THE MARSHALL SPACE FLIGHT CENTER (1993 TO 1997)

1. INTRODUCTION AND BACKGROUND OF LIFE TESTING

Life testing of selected Environmental Control and Life Support System (ECLSS) equipment began in 1992 after it was determined by Marshall Space Flight Center (MSFC) personnel that adequate life testing was not being conducted by *International Space Station* (*ISS*) hardware developers. Testing of qualifiable hardware by Boeing (the prime contractor) would not precede its launch; therefore, it would not be possible to determine design problems early enough to prevent *ISS* ECLSS startup difficulties. Life testing enabled identification of design problems in time to improve the flight hardware. Specific objectives of the life test program were:

"1. To develop a knowledge base for design requirements and criteria which affect logistics and reliability.
2. To minimize hardware development risk by providing long-duration operational histories at space station operating conditions and making the data obtained during the course of the test immediately available to the prime contractor and its hardware vendors so that the flight design can take advantage of the lessons learned and make the appropriate design changes to ensure a highly reliable ECLSS.
3. To determine specific component life characteristics and to understand their failure mechanisms for space station ECLSS hardware designs."[1]

The purpose of the Vapor Compression Distillation/Urine Processing Assembly (VCD/UPA) life test was to provide for long duration operation of the VCD/UPA at normal *ISS* operating conditions to determine the useful life of the hardware, specifically the flight-like components.[2] The VCD design has evolved considerably over the past 20 years. Since it was initially developed, improvements include changes in the peristaltic fluids pump, improved sensors, modifying the shape of the distillation centrifuge to a tapered drum, and improvements to the compressor. The materials have been upgraded to withstand the harsh environment inside the assembly, but long-term testing of a complete VCD/UPA (with flight-like components) to determine the life characteristics of mechanical components under simulated on-orbit conditions had not been done. The VCD/UPA contains mechanical design features which inherently have limited life, such as the peristaltic pumps. The life test was planned so that the VCD/UPA would be tested in the way that it will operate on orbit (with operation for a portion of each day) rather than running continuously, as the manufacturer (Life Systems, Inc. (LSI)) had done during previous testing. The on/off operation presents a more severe condition for the mechanical components and, therefore, would reveal design problems not apparent during previous testing.

2. VCD/UPA PROCESS AND HARDWARE DESCRIPTION

The VCD/UPA is a phase-change water recovery technology which will reclaim water from urine and other *ISS* wastewaters. Two VCD/UPA's were tested, designated the VCD–5 and VCD–5A. The process and hardware are described below.

2.1 VCD Process

In the VCD process, wastewater is distilled by evaporating clean water from a thin film of wastewater at low pressures (3.4 to 5.5 kPa, 0.5 to 0.8 psia) and ambient temperatures (32 to 43 °C, 90 to 110 °F). The VCD process recovers the latent heat of condensation by compressing the water vapor to raise its saturation temperature and pressure, and then condensing the vapor on a surface that is in thermal contact with the evaporator. The resulting heat flux from the condenser to the evaporator, driven by the saturation temperature difference, is enough to evaporate an equal mass of water from the wastewater, so that the only additional energy required is that necessary to compress the water vapor and overcome any mechanical and thermal inefficiencies.

As shown in figure 1, wastewater is circulated through the distillation unit (DU) by a four-section peristaltic fluids pump. One section of the pump discharges wastewater to the inner surface of the evaporator centrifuge (still) in the DU at a rate greater than the vaporization rate. As water evaporates the vapor is compressed and transferred to the condenser. As the vapor condenses it is pumped out of the DU by another section of the fluids pump and passed through a conductivity sensor. Unacceptable water, that does not meet the conductivity specifications (<150 μmho/cm), is routed to the recycle loop for reprocessing. Good quality condensate is delivered as product water. Excess wastewater is removed from the still by two sections of the fluids pump and pumped through a recycle filter tank prior to mixing with fresh wastewater and reprocessing in the still. Periodically, a purge valve is opened to remove noncondensable gases from the condenser by the purge pump and to maintain the operating pressure between 3.4 to 5.5 kPa (0.5 and 0.8 psia).

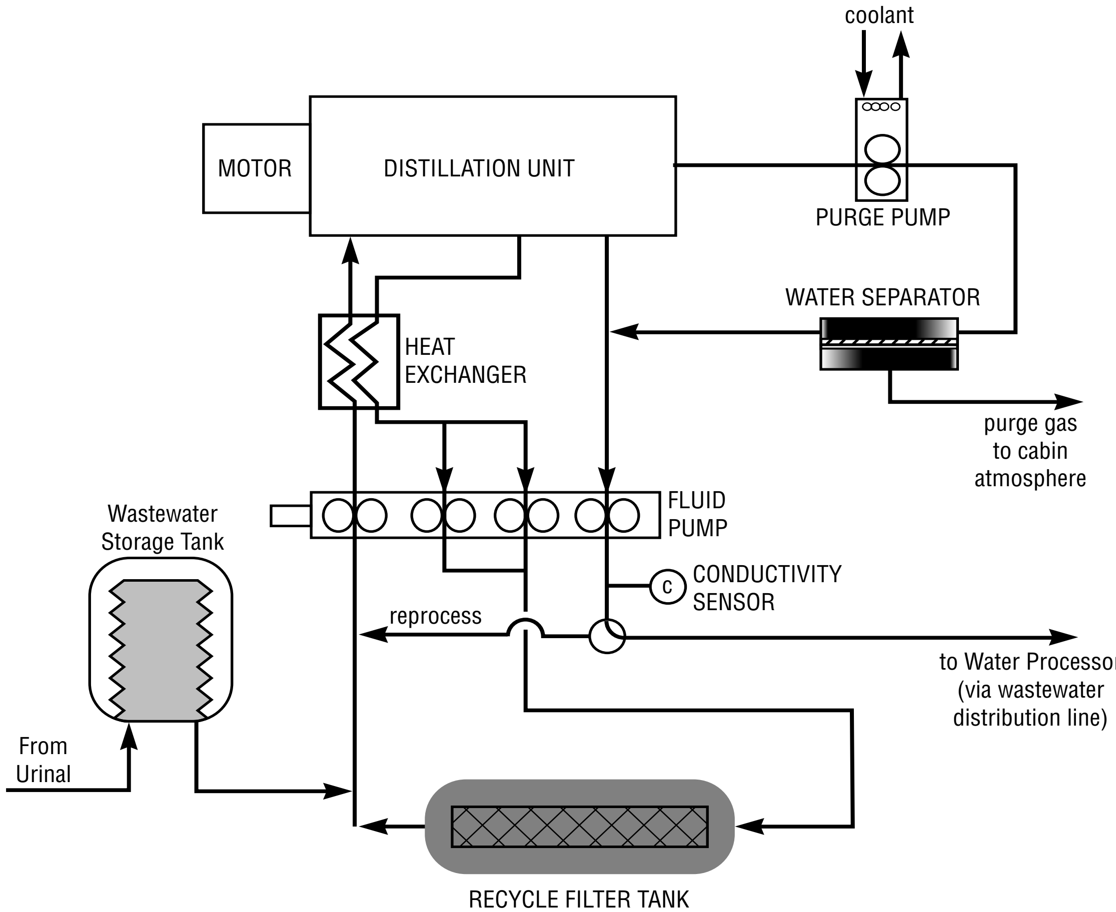

Figure 1. Schematic of VCD process.

2.2 Hardware Description and Similarity With the *ISS* UPA

The design of the VCD–5 and VCD–5A hardware is described below and the degree of similarity to the flight VCD/UPA is identified for each component.

2.2.1 VCD Hardware

Photographs of the VCD–5 and VCD–5A are shown in figures 2 and 3. As shown schematically in figure 4, the VCD–5 and VCD–5A each consist of a wastewater storage assembly (WSA), a fluids control assembly (FCA), a fluids pump assembly (FPA), a distillation assembly (DA), a recycle filter tank assembly (RFTA), a pressure control assembly (PCA), a purge pump assembly (PPA), and sensors for measuring conductivity, temperature, pressure, rotation speed, and electrical current level. These components are described below.

Figure 2. Photograph of the VCD–5.

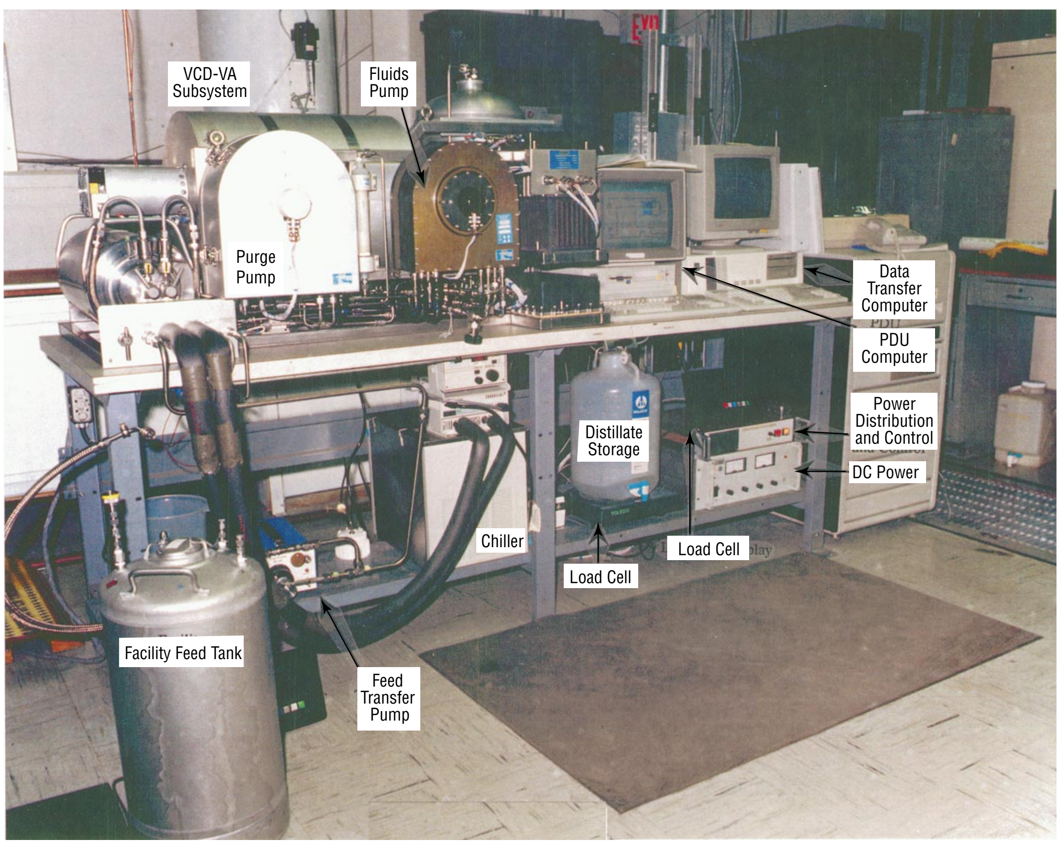

Figure 3. Photograph of the VCD–5A.

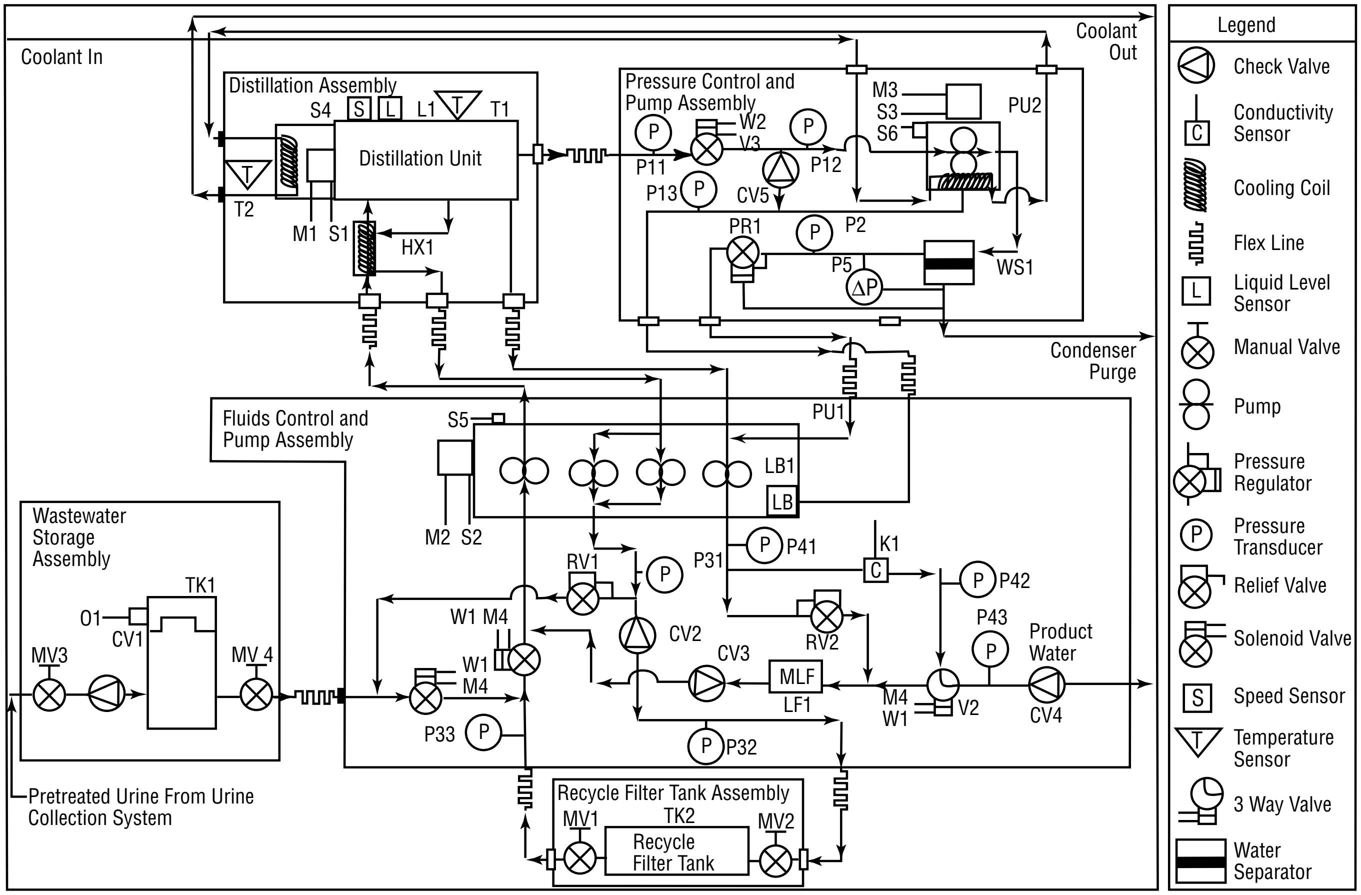

Figure 4. Schematic of VCD hardware and instrumentation.

2.2.1.1 Wastewater Storage Assembly. The WSA includes a titanium bellows tank (TK1) inside a shell in which the quantity of liquid is measured by the position of the bellows. Wastewater stored in this tank replenishes the wastewater loop as wastewater is injected into the still by the fluids pump. The WSA for the *ISS* UPA is a single, integrated mechanical component which incorporates all of the discrete components that make up the WSA in the VCD–5 or VCD–5A. The WSA for the *ISS* UPA has a sealed shell which will act as a containment device if the bellows were to leak. The sealed shell can “breathe” through a doubly redundant Gore-Tex™ membrane.

2.2.1.2 Fluids Control Assembly. The FCA consists of piping and valves that direct the flow of water into and out of the DU, and provides an interface between the fluids pump and the recycle filter tank. The FCA also includes a conductivity sensor, which monitors the conductivity of the distillate, and a valve to direct the distillate to the product water outlet or to the recycle line for reprocessing. The FCA for the *ISS* UPA is an integrated mechanical component which incorporates in one housing all of the discrete components that make up the FCA in the VCD–5 or VCD–5A.

2.2.1.3 Fluids Pump Assembly. The FPA includes a four-section peristaltic fluids pump (PU1), as shown schematically in figures 1 and 4, which continually circulates wastewater through the evaporator side of the DU (one section supplies wastewater and two sections remove excess wastewater) and the recycle filter tank, and removes the product water from the condenser side of the DU (one section).

Having two sections pumping water out of the DU ensures that the outlet capacity is always greater than the inlet rate, which avoids flooding the still. A motor drives the fluids pump at 8 rpm through a Harmonic Drive. The tubes of the pump are made of Norprene®.

The FPA of the *ISS* UPA and the VCD–5 and VCD–5A are identical in size and function. Differences are that the *ISS* UPA FPA housing is made of titanium whereas the VCD–5 and VCD–5A FPA housings are aluminum, and the *ISS* UPA FPA uses a 120 volts, direct current (Vdc) brushless motor, whereas the VCD–5 and VCD–5A use 28-Vdc brushless motors. The major processing function of the tubes and rollers is the same. Figure 5 shows schematically the design concept and operation of a peristaltic pump. The pump drive is described in section 2.2.1.7.1.

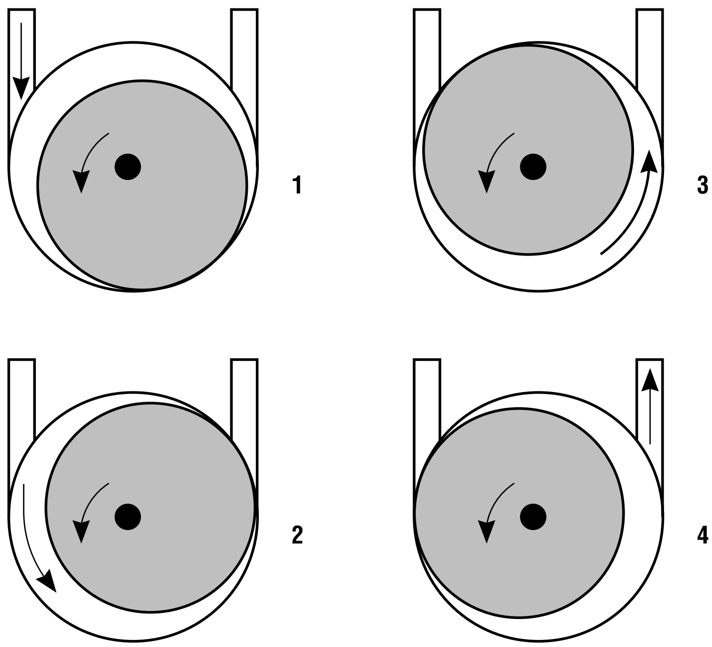

Figure 5. Peristaltic pump design concept and operation.

2.2.1.4 Distillation Assembly. The DA, shown schematically in figure 6, includes the DU, which is a rotating drum centrifuge. The DU rotates at 185 rpm to spread the incoming wastewater into a thin film from which water can evaporate easily at ambient temperature and reduced pressure (see also section 2.1). The water vapor is transferred to the outside of the drum through a compressor, where it condenses as clean water. The DA of the *ISS* UPA and the VCD–5 and VCD–5A are identical in size and function. The only differences are that the *ISS* UPA DU is made of titanium, whereas the VCD–5 and VCD–5A DUs are stainless steel, the *ISS* UPA DA uses a 120 Vdc brushless motor, whereas the VCD–5 and VCD–5A use 28 Vdc brushless motors, and the *ISS* UPA demister is a nonmetallic membrane-type, whereas the VCD–5 and VCD–5A have steel wool-type demisters. The demister ensures that only vaporized water is drawn into the compressor by blocking any droplets of wastewater.

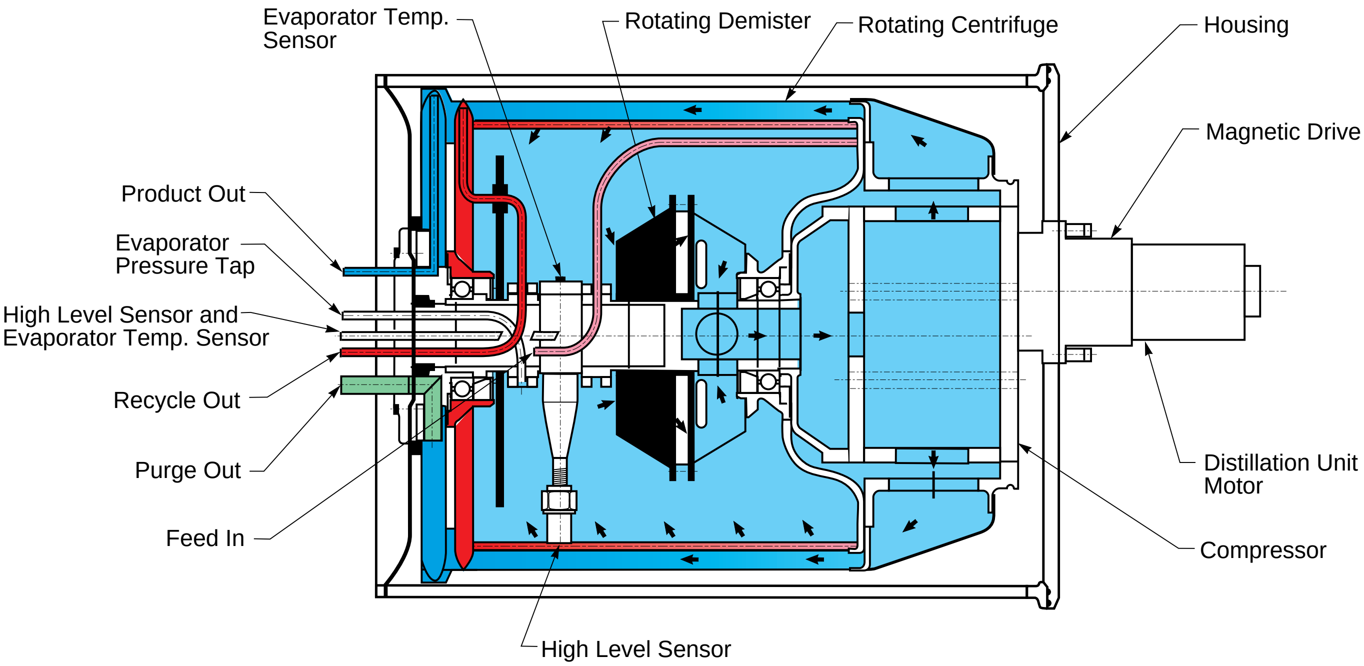

Figure 6. VCD distillation assembly schematic.

2.2.1.5 Recycle Filter Tank Assembly. The RFTA includes a 22 L (0.78 ft^3) tank with filters to remove solids from the wastewater before it is recirculated through the distillation unit. The tank and filter components are shown disassembled in figure 7. When the brine solids concentration reaches about 25 percent in the recycle filter tank, the tank is removed for cleaning and the filters are replaced. These filters are shown in figure 8. The filters used for most of the life testing were dual 25 µm pore size spiral wound filters, with a noncantilevered support (i.e., supported at each end). For testing of the VCD–5 during part of the Water Recovery Test (WRT) Stage 10,[3] a single flight-like 10 µm pore size pleated filter was used, with a cantilevered support, as shown in figure 7. Also, a 30 µm pore size pleated filter was used during part of the WRT Stage 10 to compare the results. The brine was discarded during cleaning of the tank. During flight operation the entire tank will be replaced as an orbital replaceable unit (ORU) and the used tank will be returned to Earth for cleaning and filter replacement.

Figure 7. VCD/UPA RFTA disassembled (showing single filter configuration).

Figure 8. VCD/UPA filters (top: 25 µm pore size, bottom: 10 µm pore size).

The RFTA for the *ISS* UPA is an integrated mechanical component which incorporates all of the discrete components that make up the RFTA's in the VCD–5 or VCD–5A. Major differences are that the *ISS* UPA RFTA uses a single cantilevered 10 µm filter element while the VCD–5 and VCD–5A use a dual noncantilevered 25 µm filter design (except as noted above), and that the *ISS* UPA tank is made of titanium, while the VCD–5 and VCD–5A tanks are stainless steel.

2.2.1.6 Pressure Control Assembly. The PCA consists of piping and valves to control the pressure in the still. Also included is a gas/liquid separator (WS1) to remove any water from the purge gases and return it to the product waterline. The primary function of the PCA is to periodically purge the DU of noncondensable gases that enter as dissolved or free gases with the wastewater feed. As noncondensable gases increase in the DU condenser, the pressure will increase, which will make the compressor work harder and reduce the overall performance. The PCA monitors this pressure increase and activates the PPA when a purge is required. The PPA compresses the noncondensable gas with water vapor to pressures above ambient, condensing the water vapor. From there, the noncondensable gas and condensate pass through a membrane gas/water separator where condensate is recovered and routed back into the product water stream. The noncondensable gases are released to the atmosphere.

The PCA for the *ISS* UPA is an integrated mechanical component which incorporates in one housing all of the discrete components that make up the PCA in the VCD–5 and VCD–5A.

2.2.1.7 Purge Pump Assembly. The PPA is essentially identical with the FPA, consisting of a four-section peristaltic-type purge pump (PU2) which removes gases from the condenser side of the DU and evacuates the casings of the fluids pump and itself. The four sections operate in parallel through inlet and outlet manifolds. The only differences with the fluids pump are a cooling jacket around the purge pump and the speed at which the pump operates (25 rpm versus 8 rpm for the fluids pump). Figure 9 schematically shows the basic design concept and connections of the PPA. The pump drive is described in section 2.2.1.7.1. A membrane-type water separator removes condensed water from the purge pump outlet stream. The water is combined with the product water from the DU and the air is returned to the cabin atmosphere.

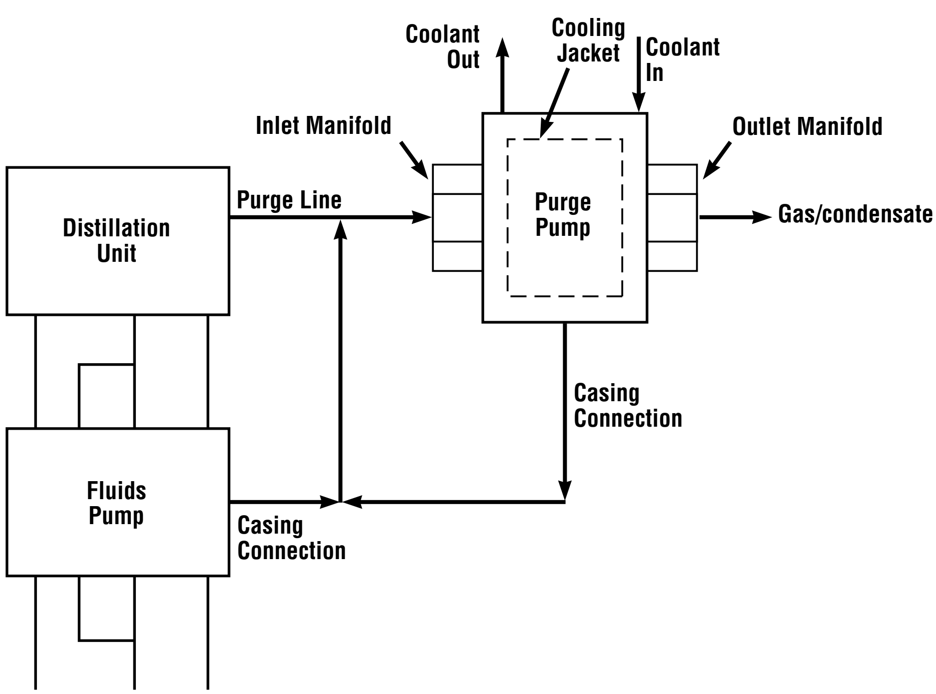

Figure 9. Purge pump design concept and connections.

The PPA of the *ISS* UPA and the VCD–5 and VCD–5A are identical in size and function. Differences are that the *ISS* UPA PPA casing and cooling jacket are made of titanium, whereas the VCD–5 and VCD–5A PPA casings and cooling jackets are aluminum; and the *ISS* UPA PPA uses a 120 Vdc brushless motor, whereas the VCD–5 and VCD–5A use 28 Vdc brushless motors. The function of the tubes and rollers is the same, as shown in figure 5.

2.2.1.7.1 Harmonic Drive. The FPA and PPA drive gearing is made by Harmonic Drive Technologies.[4] The Harmonic Drive, shown schematically in figure 10, consists of concentric components that transmit torque in less space and with a smaller support structure than conventional gearing. The components consist of a circular rigid internal spline gear, an elliptical ball bearing wave generator, and an elliptical nonrigid external flexspline gear. Benefits include low or zero backlash, efficiencies typically ranging from 80 to 90 percent, torque transfer equivalent to other types of drives that are twice as large, positional accuracy and repeatability, long life, and high reliability. The material of the rigid spline and the flex spline is stainless steel. As used in the VCD, the Harmonic Drive is not subjected to a harsh environment, and the temperatures and pressures around the Harmonic Drive are typical ambient conditions. The normal speed of operation is 8 rpm for the fluids pump and 25 rpm for the purge pump.

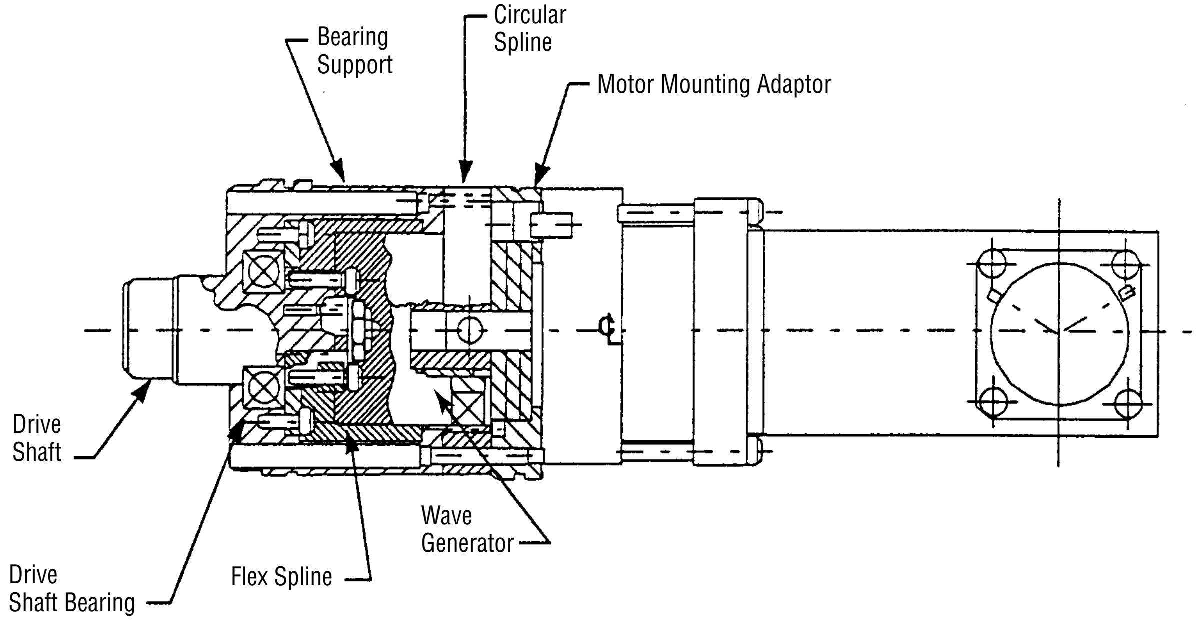

Figure 10. Harmonic Drive.

The use of Harmonic Drives in VCD's is summarized in tables 1 and 2.

Table 1. History of the use of Harmonic Drives in VCD's.

VCD Designation	Harmonic Drive Use		Comments
	Fluids Pump	Purge Pump	
VCD–4	√		Technology Demonstrator VCD
VCD–4A	√		
VCD–4B	√	√	First VCD to Have a Peristaltic Purge Pump With Harmonic Drive
VCD-6	√	√	
P VCD	√	√	Converted From the VCD–4B
VCD–5	√	√	Converted From the POST VCD
VCD–5A	√	√	Converted From the VCD–4

Table 2. Harmonic Drive operating history (as of May 25, 1993).

VCD Designation	Harmonic Drive (HDC–1C–100–2) in Fluids Pump			Harmonic Drive (HDC–1C–60–2) in Purge Pump		
	Drive #	Run Time, hr (1)	No. of Start/Stop	Drive #	Run Time, hr (2)	No. of Start/Stop
VCD–4A	1	8,084	77	-	-	-
	2	3,308	4			
	3	14,678	63			
VCD–5 (3)	1	5,962	92	1	993	29,810
VCD–5A (4)	1	1,724	<100	1	127 (6)	3,810
	2	362	N/A			
VCD-6	1	370	50	1	191 (5)	1,850

Notes: (1) Time to failure, unless still operating
(2) Calculated based on 2 min per 12 min duty cycle without the startup time
(3) Converted from the VCD–4B (5,400 hr as VCD–4B, 562 hr as VCD–5)
(4) Converted from the VCD–4 (1,324 hr as VCD–4, 762 hr as VCD–5A)
(5) Actual time
(6) Based on 762 hr (362 + 400 hr) of operation as the VCD–5A

2.2.1.8 Instrumentation and Monitoring. The instrumentation identified in figure 4 and required to monitor the operation and performance of the VCD–5 and VCD–5A for life testing is listed in table 3. Data from these instruments were monitored via computer using the Systems and Components Automated Test System (SCATS),[5] and the Payloads and Components Real-time Automated Test System (PACRATS)[6] during the WRT Stage 10. The *ISS* UPA will have similar instrumentation and the sensors will have redundancy built-in for fault tolerance.

2.2.2 Flight-like Components

The VCD–5 and VCD–5A were flight-like as indicated in table 4. Considering the components by *ISS* UPA ORU, the function, capacity, material, and final design aspects are compared with the *ISS* UPA. The controller for the VCD–5 and VCD–5A is a 400 Series Life Systems controller. The controller for the *ISS* UPA is the next generation controller, with a new design having additional capabilities, particularly with regard to self-diagnostics, e.g., fault detection and isolation.

Table 3. VCD–5 and VCD–5A instrumentation list.

Designation on Figure 4	Measurement ID	Description
	vcl1	Recycle Filter Tank Concentration (Calculated)
I1	vi1	Compressor Motor Current
K1	vk1	Product Water Conductivity (Triple-Redundant Sensors, Averaged Value)
L1	vl1	Liquid Level Sensor in the Distillation Unit
Q1	vq1	Wastewater Supply Tank Quantity
P1	vp1	Condenser Pressure
P2	vp2	Compressor Differential Pressure
	vp3	Wastewater Inlet Pressure to the Recycle Filter Tank
	vp4	Outlet Pressure Of Product Water From the Fluids Pump
P5	vp5	Differential Pressure Across the Gas/Liquid Separator
	vqlb	Wastewater Supply Quantity Average (lb)
	vq4	Total Wastewater Processed (Calculated)
	vq5	Recycle Fill Quantity
S1	vs1	Compressor Speed
S2	vs2	Fluids Pump Motor Speed
S3	vs3	Purge Pump Motor Speed
S4	vs4	Distillation Centrifuge Speed
T1	vt1	Compressor Outlet Temperature
	vt2	Coolant Temperature
	vt4	Condenser Temperature
Related Facility Instrumentation		
	VT5	Cooled Water Supply Temperature
	VT6	Cooled Water Return Temperature
	FP01	High Bay Pressure
	FT01	High Bay Temperature

2.3 Upgrades from Previous VCD's

The VCD–5 and VCD–5A are the designations given to refurbished earlier-generation VCD's, as indicated in table 2. During development of the *ISS* ECLSS design, the following additional requirements were levied on the UPA and incorporated in the VCD–5 and VCD–5A:

1. Addition of a wastewater storage assembly (Facility wastewater tank used for the VCD–5A)
2. Addition of a coolant jacket to the PPA
3. Change in software operational aspects, i.e., operating modes, mode transitions, and process control loops.

Table 4. VCD–5 and VCD–5A flight-like characteristics .[7]

VCD–5 and VCD–5A ORU/component	Flight-Like Characteristics (a)			
	Function	Capacity	Material	Design
Pressure Control Assembly				
Membrane Separator	√	√	√	
Pressure Sensors	√	√		
Valves	√	√		
Check Valve	√	√		
Microbial Filter	√			
QDs (b)				
Housing (b)				
Fluids Control Assembly				
Conductivity Sensor	√	√		
Pressure Sensor	√	√		
Relief Valves	√	√		
Check Valves	√	√		
Valves	√	√		
Microbial Check Valve (not on the 5A)	√	√	√	
QDs (b)				
Housing (b)				
Controller				
Controller	√	√		
Wastewater Storage Assembly				
Bellows	√	√		
Position Indicator	√	√	√	
Shell			√	
Check Valve	√			
Isolation Valve (b)				
QDs (b)				
Recycle Filter Tank				
Valves	√	√		
Filter	√			
Shell	√			
QDs (b)				
Distillation Assembly				
Distillation Unit	√	√		
Motor	√			
Gear	√	√	√	√
Magnetic Drive	√	√	√	√
Bearings	√	√	√	√
Pulleys	√	√		√
Insulation	√			
Heat Exchanger	√			√
Plumbing	√			
Speed Sensor	√			
Liquid Level Sensor	√	√	√	

Table 4. VCD–5 and VCD–5A flight-like characteristics .[7] (Continued)

VCD–5 and VCD–5A ORU/component	Flight-Like Characteristics (a)			
	Function	Capacity	Material	Design
Distillation Assembly (Continued)				
Compressor	√	√	√	√
Temperature Sensor	√			
Demister	√	√		
Shaft Assembly	√	√		
End Hub	√	√		
Stationary Bowl	√	√		
Front Plate	√	√		
QDs (b)	√	√		
Fluids Pump Assembly				
Pump	√	√	√	√
Motor	√	√		
Harmonic Drive	√	√	√	√
Shell	√	√		
Tubing	√	√	√	√
Speed Sensor (S2)	√	√		
Speed Sensor (b)				
QDs (b)				
Purge Pump Assembly				
Pump	√	√	√	√
Motor	√	√		
Harmonic Drive	√	√	√	√
Shell	√	√		
Tubing	√	√	√	√
Cooling Jacket	√	√		
Speed Sensor (S2)	√	√		
Speed Sensor (b)				
QDs (b)				
Membrane Gas/Liquid Separator	√	√	√	

Notes: (a) A √ indicates that the VCD–5 and VCD–5A component is like the ISS UPA design and is therefore "flight-like." If no √ is present then the component is not "flight-like."
(b) This component is not used by the VCD–5 or the VCD–5A.

2.3.1 VCD–5 History

The VCD–5 is the designation given to the refurbished VCD used in the Boeing Predevelopment Operation Systems Test (POST) at MSFC. The POST VCD had previously been the VCD–4B, the first VCD to include a purge pump in the design and to use a Harmonic Drive on the purge pump. The VCD–5 life test began on May 6, 1993. The VCD–5 was used in Stages 9 (July 19, 1994 to December 21, 1994) and 10 (October 1, 1996 to March 27, 1997) of the WRT. [3, 8]

2.3.2 VCD–5A History

The VCD–5A is the designation given to the refurbished VCD used in the Comparative Test (designated the VCD–4) in 1990 to compare the VCD with the Thermoelectric Integrated Membrane Evaporation System (TIMES), previously baselined for use on *ISS*.[9] The VCD–4 was not the final flight configuration, but allowed performance characterization of the VCD components. The VCD–4 was upgraded to be functionally identical with the flight design at which time it was redesignated VCD–5A. The hardware modifications included design improvements to meet the additional requirements. The VCD–5A was checked out in early 1993 in Building 4755 at MSFC and life testing began on January 12, 1993. A purge gas test was conducted in 1996 using the VCD–5A.

As a result of information gained during fabrication and testing of the VCD–4, the following design improvements were made for the VCD–5A:

1. Retrofit of the fluids pump to provide dual support (two bearings) for the shaft, rather than the previous cantilevered design
2. Replacement of the commercial vacuum pump with a dual support peristaltic purge pump
3. Change from truly tubular weld fittings to Parker weld fittings
4. Change from the commercial conductivity sensor to an LSI conductivity sensor
5. Replacement of the helicoil tube-in-shell recuperative heat exchanger with a tube-type heat exchanger
6. Addition of a static membrane gas/water separator assembly
7. Addition of fluids pump tubing overpressurization protection.

3. TEST FACILITY DESCRIPTION

The VCD/UPA life testing was performed at MSFC in Building 4755, in the ECLS test facility shown in figures 11 and 12. The test facility provided all necessary utilities and data collection and monitoring capabilities. The VCD–5 was located next to the End-use Equipment Facility (EEF) and the VCD–5A was located in the northwest corner of the north high bay. Urine was collected in the EEF (as shown in figure 13) and a restroom, and pretreated using Oxone® (Oxone is a registered trademark of the DuPont Company) and sulfuric acid (in liquid form and, later, in solid tablet form as planned for use on *ISS*) prior to processing in the VCD–5A. The EEF was designed, built, and integrated with the ECLSS WRT to provide wastewater typical of that expected to be produced onboard *ISS*.[8, 10]

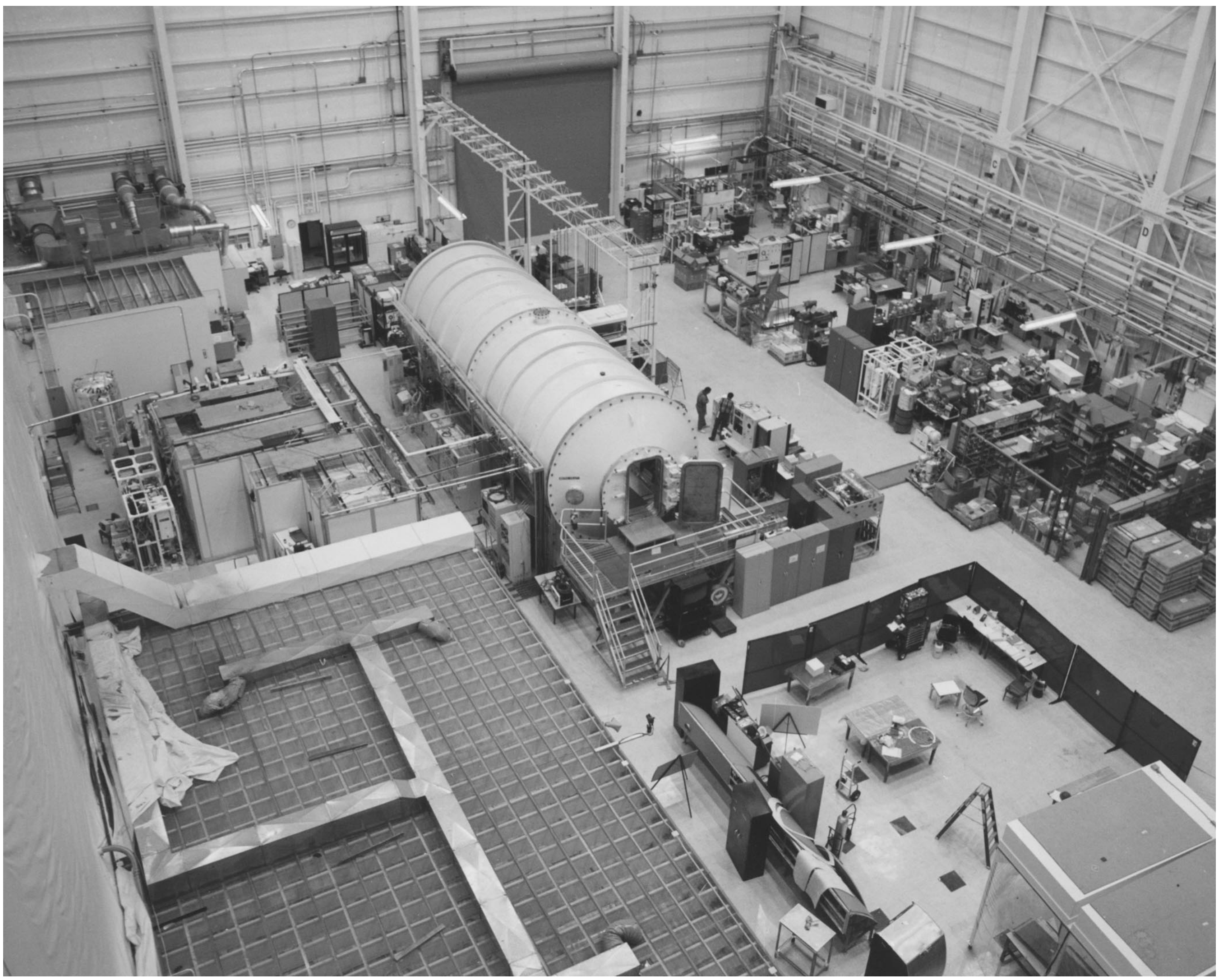

Figure 11. ECLS test facility at MSFC.

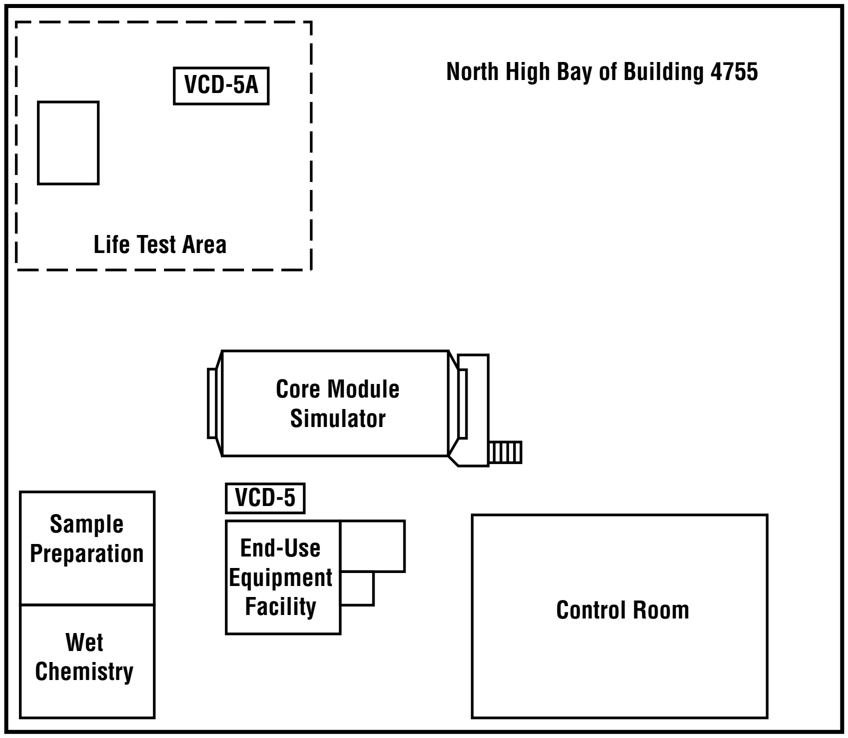

Figure 12. Schematic of the ECLS test facility at MSFC.

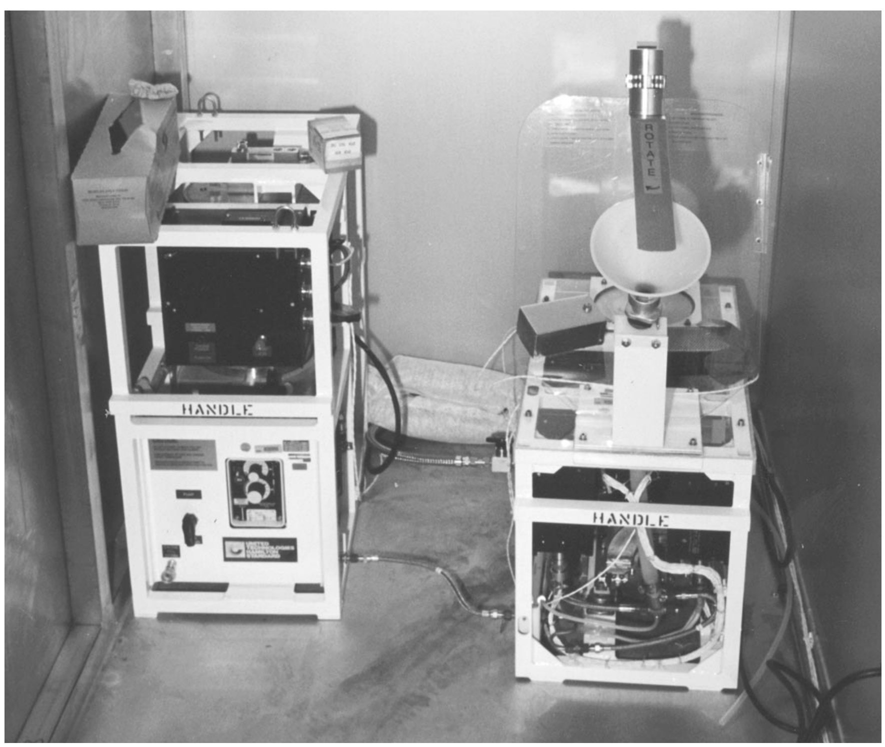

Figure 13. EEF urinal.

4. TEST DESCRIPTION AND PERFORMANCE

The specific purpose for testing the VCD/UPA, the operating procedures, and summaries of the testing performance are described below.

4.1 Test Purpose

The purpose of the VCD/UPA life testing was to determine the useful lifetimes of specific components that were considered to be subject to mechanical wear, and to monitor the processing performance over an extended period of flight-like operation. Performance was assessed using simulated flight operation conditions, with the exception of microgravity.

4.2 Operating Procedures

The procedures for operating the VCD–5 and VCD–5A were different to evaluate somewhat different aspects of operation. The VCD–5 was activated for two or three cycles each day with reduced run times to gather data on startup and shutdown effects on the hardware and to accelerate mechanical wear. Wastewater processing (production rate and quality of product water) was not monitored. When the VCD–5 was incorporated in the WRT Stage 10, the operation was changed to more closely simulate flight operation times and the production rates and quality of product water were monitored. The VCD–5A was operated once each work day with processing run times as expected on-orbit (approximately six hours each day) and the production rate was monitored to evaluate long-term performance characteristics.

4.3 Components Tested

The specific components of the VCD/UPA that were the subject of the life testing are the wastewater storage tank, peristaltic fluids pump, distillation unit, recycle filter tank, gas/liquid separator, and peristaltic purge pump. These components are described in section 2.

4.4 VCD–5 Testing

The VCD–5 life test began on May 6, 1993 and ran until February 16, 1994, for a total of 204 test days. A Gantt chart of the VCD–5 operation during this period is shown in figure 14. Significant test events and anomalies are described in section 4.4.1. Additional testing was performed during the stage 9 and WRT Stage 10.[3, 8] The WRT Stage 10 performance of the VCD–5 is described in more detail in section 4.4.2. Plots of typical operating conditions for the compressor temperature (T1), compressor motor current (I1), and condenser pressure (P1) are shown in figures 15, 16, and 17, respectively. This testing revealed several problems that can be directly attributed to quality control problems. Most anomalies were related to low centrifuge speed, high compressor temperatures, and high condenser pressures. Conditions that recurred, but were not listed as "anomalies," are short-term high product water conductivity and blockage of the gas/liquid separator and pressure regulator with Norprene® particles.

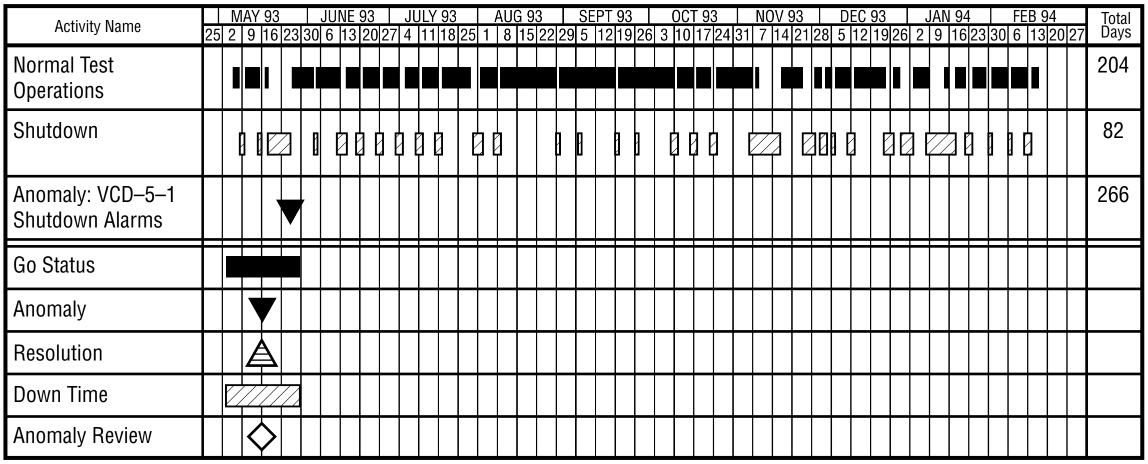

Figure 14. Gantt chart of VCD–5 operation.

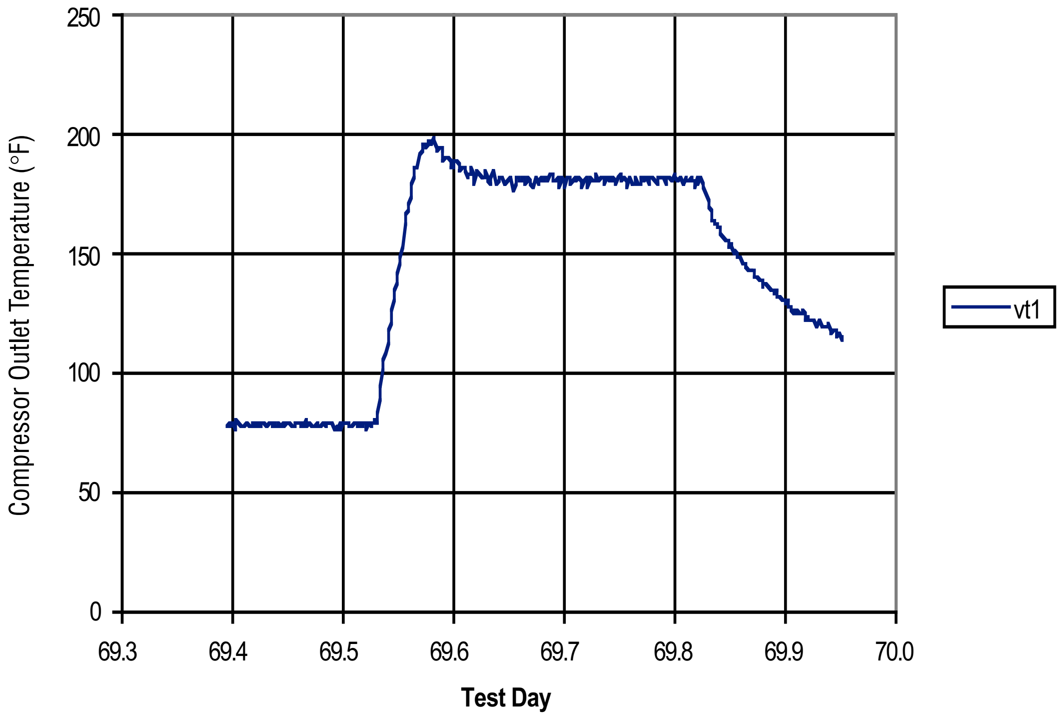

Figure 15. VCD–5 typical compressor temperature (T1).

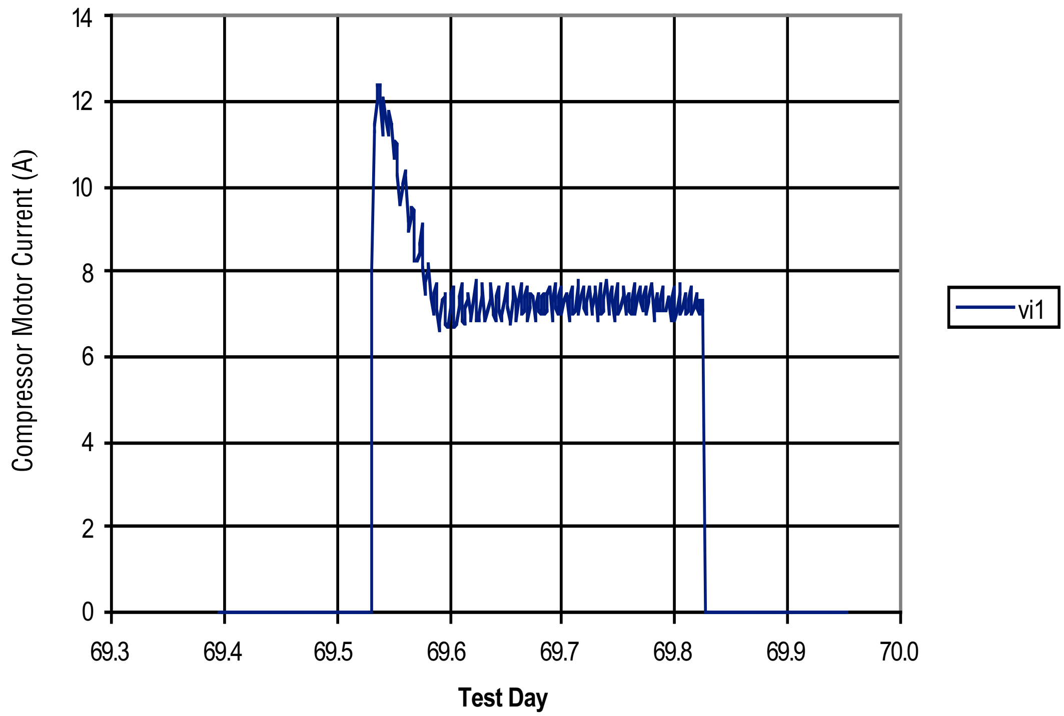

Figure 16. VCD–5 typical compressor motor current (I1).

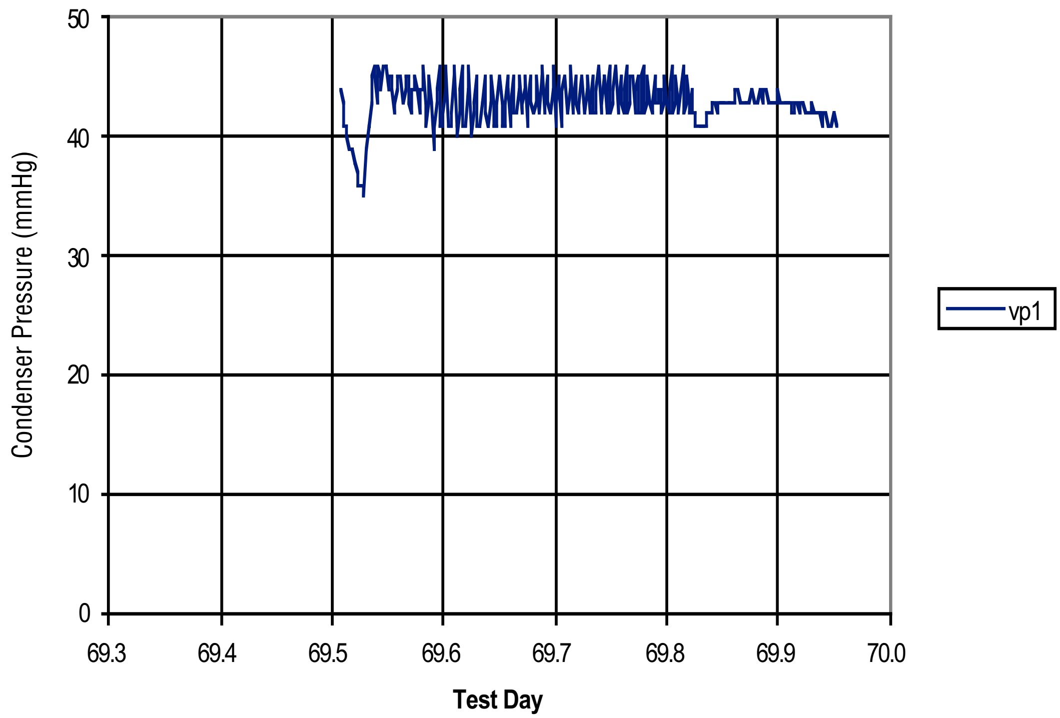

Figure 17. VCD–5 typical condenser pressure (P1).

The results of laboratory analyses of product water and brine samples are listed in table 5. The product water quality was within specification for all parameters for all of these samples (150 µmho/cm conductivity, pH of 3 to 8, and total organic carbon (TOC) <50). The brine analysis shows an increasing solids content, as expected. The exact percentage of solids is difficult to determine. The three methods used to calculate the percent solids show significant variation in calculated percent, but the trend is the same for each of the methods.

Table 5. VCD–5 product water and brine compositions.

Characteristic	Test Day / Date / Units	122	126	131	138	143	149	152	161	168
	Date					11/8/93	11/22/93			12/20/93
Product Water Composition										
pH			3.8	3.8	3.8		3.8	3.8	3.8	4
Conductivity	µmho/cm		63	63.2	70.3		61.5	64	68.7	48.8
Turbidity	NTU		0.3	<0.1	1.3		<0.1	<0.1	0.1	0.1
TOC	mg/L	15.6	17.1	22.6	20.8	13				
TIC	mg/L	1	<1.0	2.01	<1.0	2.04				
TC	mg/L	17	17	25	21	15				
Particles:										
0-5 µm Particles	Particles/mL	89.6	176	110	152	239	157	321		41.6
5.1-10 µm Particles	Particles/mL	5.52	51.5	12.8	13.4	25.7	10.2	27.1		5.5
10.1-40 µm Particles	Particles/mL	<1.0	19.9	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0
40.1-100 µm Particles	Particles/mL	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0
100.1-500 µm Particles	Particles/mL	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0
Brine Composition										
Refractive Index		1.347	1.350	1.355	1.359	1.345	1.35	1.353		1.346
Specific Gravity		1.049	1.063	1.079	1.097	1.039	1.061	1.067		1.042
Solids Conc. (BS)*	%	9.92	12.06	15.63	18.49	8.49	12.06	14.20		9.21
Solids Conc. (UJ)*	%	7.45	9.08	11.8	13.97	6.36	9.08	10.71		6.91
Solids Conc. (UP)*	%	9.22	11.11	14.26	16.77	7.96	11.11	13.00		8.59

Double vertical lines indicate cleaning of the recycle filter tank and replacement of the filters.

*Note: The Solids Concentration is calculated based on the refractive index and specific gravity of the brine. Three different methods were compared to calculate the % solids: BS = Boeing Services, UJ = Umpqua Jolly, and UP = Umpqua Putman.

4.4.1 VCD–5 Test Events and Anomalies

The significant events and anomalies that occurred during testing of the VCD–5 are summarized in table 6.

The first anomaly related to difficulty at startup with reaching the normal drive speed for the centrifuge, high compressor temperatures, and low gas/liquid separator pressures. The low centrifuge speed was a particularly vexing problem and there were numerous efforts to correct this, including adjusting the software. When the other problems led to disassembling the VCD–5 it was found that the drive belt for the centrifuge had been incorrectly installed by the hardware supplier, resulting in the low speed.

A recurring event was high conductivity of the product water. The procedure was changed to include disconnecting the conductivity sensor at the beginning of a processing cycle until the timer reset for up to 15 min of additional reprocessing. One effect of this is to reduce the performance by reprocessing water that meets specification.

Leakage occurred which limited the ability of the purge pump to maintain a vacuum in the still. As a result, the pumping rate could not keep pace with the collection of noncondensable gases in the condenser. Increasing the duration of the purge helped, but eventually a facility vacuum pump was needed to ensure adequate vacuum. One source of leakage was the drive shaft of the pump.

The Data Acquisition System (DAS) was found to have a short, which was repaired the same day it was found. This did not involve flight-like components.

The pressure regulator and the gas/liquid separator were found to be blocked with particles of Norprene® spalling from the purge pump tubes. These components were cleaned and reinstalled. (Further investigation of the purge pump tubing problem showed that spalling had occurred in the VCD–5A as well. See section 4.5.1 for more information.)

High compressor temperature alarms occurred repeatedly during the life test. This was also related to leakage. Use of facility vacuum to assist the purge pump helped to reduce these alarms, but the combination of problems led to stopping the test on November 9, 1993 until repairs could be made on January 13, 1994. Beginning on test day 20, a fan was used to cool the compressor motor from 66 to 42 °C (151 to 108 °F) which eliminated high temperature shutdowns. Also, software changes were made to enable longer purge times since air in the wastewater feed was a factor. Compressor gear wear was also a factor and during the repairs the compressor gear backlash was found to be 0.254 to 0.305 mm (0.010 to 0.012 in.) versus 0.076 to 0.102 mm (0.003 to 0.004 in.) when new. This is considered normal wear for a total running time of 7,400 hr, but near the maximum desired backlash. Particles of Vespel® from the compressor gear were also present in the product water due to gear wear.

To prepare the VCD–5 for the WRT Stage 9, the accelerated life test was discontinued on February 17, 1994, shortly after the repairs were made (on January 13, 1994) that resolved some of the anomalies. Although the accelerated testing proved valuable, the decision to discontinue it was based upon the continuing problems with the VCD–5. Repairs were made to correct the remaining problems before continuing the testing (the WRT Stages 9 and 10).

The second anomaly occurred during the WRT Stage 9, when the CPU failed. (This was not a flight-like CPU.) The multiplexer card was replaced and testing continued.

The third anomaly— recurring high compressor outlet temperatures at the beginning of each processing cycle—also occurred during the WRT Stage 9, as well as during previous testing . The cause for this is gravity-related, since any free gas entrained in the wastewater collects at the top of the tank, where the outlet is located. This would not happen on-orbit due to more even distribution of free gas throughout the wastewater. Thus, at the beginning of a cycle this gas is injected into the still before the wastewater. Since the gas does not provide evaporative cooling, like the wastewater does, the compressor temperature increases until wastewater reaches the still.

The fourth anomaly occurred during the WRT Stage 10, when the motor speed controller malfunctioned. The motor speed controller was replaced by LSI. The cause of the malfunction was not identified. The controller was sent to the manufacturer for repair, but was apparently lost.

The fifth anomaly was the presence of Vespel® particles in the product water. This indicated deterioration of the Vespel® gear and the gear was replaced (see sec. 4.4.2). The quantity of Vespel® particles found in the product water then decreased as residual particles were swept from the water lines.

The sixth anomaly was the recurring high conductivity of the product water at the beginning of a processing cycle. The cause of the high conductivity readings was not specifically identified until much later (see section 4.4.1.1), although, when the sensor was cleaned, particles of Vespel® were found in the sensor and housing. Other possible factors are gas bubbles in the product water stream or leakage of unprocessed wastewater into the fluids pump housing. The conductivity quickly decreased as processing proceeded (see sec. 4.4.2.1.6).

The seventh anomaly was the recurring high temperatures at the compressor outlet (see also anomaly three).

At the beginning of a processing cycle, high temperatures occurred for about 40 minutes, before coming down to the desired range. The temperature was measured at the outlet of the compressor (vt1) and indicated the temperature close to the gears. The temperature spiked above the alarm set-point of 93 °C (200 °F) due to the excessive load on the compressor and/or inadequate cooling of the gears. The high temperatures were eliminated after a sample port was added at the outlet of the wastewater supply tank, which enabled free gas to be removed during sample collection before the wastewater entered the still. This is discussed further in section 4.4.2.

The eighth anomaly was failure of the purge pump, near the end of the WRT Stage 10. Facility vacuum was used for the completion of the test. The pump was then disassembled, but no obvious failure was apparent. Upon reassembly the pump worked properly.

4.4.1.1 VCD-5 Troubleshooting. In 1998, when the VCD-5 was being prepared for WRT Stage 11 integrated testing, the fluids pump was disassembled to investigate the problems with high conductivity at start-up and occasionally at other times, and the difficulty maintaining sufficiently low purge pressures. The housing of the pump (made of anodized aluminum) was found to be corroded inside. None of the tubes had failed, but one of the clamps holding a recycle-loop tube (on the pressure side of the pump) was very loose, which could allow small amounts of brine to be pumped into the housing and then vacuumed out by the purge pump when the housings were evacuated. This would explain the high conductivity of the product water and the pump housing leakage seen during Stage 10. In addition, one of the O-rings fell apart when it was removed, and looked kinked like it had not been installed properly or was the wrong size. This pump was last serviced by LSI possibly before Stage 9.

Table 6. VCD–5 significant events and anomalies.

Bold indicates that a flight-like component is affected

Anomaly Number	Event/Anomaly Description	Date Occurred	Actionee	Date Closed Out	Notes/Action to Resolve Anomaly
	Life test began	5/7/93			
VCD–5-1	Recurring shutdowns due to low centrifuge speed (S4), low gas/liquid differential pressures, and high compressor temperatures (T1).	5/19/93 1/11/94 recurring problem	Hutchens, Long, Salyer	1/13/94 5/25/94 7/19/94	LSI field service on 1/12/94 corrected drive belt that had been misaligned during assembly. LSI field service on 5/23/94 made adjustments, recalibrated sensors, fixed leaks, and cleaned components. LSI field service on 7/19/94 replaced faulty hardware and fixed leaks in the fluids pump.
	High product water conductivity alarms, recurring problem.	5/26/93 recurring problem	Hutchens, Long, Salyer		The procedure was changed so that the conductivity sensor is disconnected at the beginning of a processing cycle until the timer resets for up to 15 minutes of additional reprocessing.
	Leak found in pump housings	6/4/93	Hutchens, Long, Salyer	6/4/93	Purge duration increased.
	Short in the Data Acquisition System	8/2/93	Hutchens, Long, Salyer	8/2/93	Repaired.
	Blockage of pressure regulator and gas/water separator.	N/A	Hutchens, Long, Salyer	1/13/94	Norprene® particles found in the pressure regulator and gas/water separator. These components were cleaned and reinstalled.
	High compressor temperature alarms.	11/4/93 recurring problem	Hutchens, Long, Salyer	2/16/94	Facility vacuum used to assist the purge pump.
	Test stopped due to low S4, low P5, and high T1	11/9/93			
	Test restarted	11/16/93			
	Repairs made	1/13/94			Drive belt reinstalled correctly, gas/liquid separator and pressure regulator cleaned of Norprene® particles and reinstalled.
WRT Stage 9					
VCD–5-2	CPU failure	9/11/94	Hutchens, Long	11/9/94	Multiplexer card replaced.
VCD–5-3	High compressor outlet temperature (T1)	9/11/94	Hutchens, Long	12/22/94	High pressures caused by urinal interface.
WRT Stage 10					
VCD–5-4	Motor speed controller malfunction.	1/1/96	Hutchens, Long, Salyer	6/27/96	Motor speed controller replaced by LSI.
VCD–5-5	Vespel® particles found in product water.	10/30/96	Wieland, Long	11/6/96	Vespel® gear replaced.
VCD–5-6	Continued high conductivity (K1) alarms.	10/31/96 recurring	Hutchens, Long	10/31/96	Cleaned K1 sensor and sensor housing. This was resolved in 5/98 with the discovery of a corroded fluids pump housing—Pump was repaired.
VCD–5-7	Compressor outlet temperature (T1) high, due to gas entering the still at the beginning of a cycle.	11/4/96	Wieland, Long	12/9/96	The cause was air being injected into the still at the beginning of each cycle. A sample port was added at the outlet of the wastewater supply tank. During sample collection, free gas is released before wastewater enters the still.
VCD–5-8	Purge pump failure	3/21/97	Wieland, Long	3/24/97	Facility vacuum was used until conclusion of the WRT Stage 10. The pump was then disassembled, but no obvious failure was apparent. Upon reassembly, the pump worked properly.

The housing was cleaned and found to be severely damaged. The sealing surfaces were corroded to the point of significant leakage of air into the pump. For the flight VCD the pump housings will be made of titanium.

4.4.2 VCD–5 Performance During the WRT Stage 10

Prior to beginning the WRT Stage 10, several modifications were made to the VCD–5. These modifications consisted of installing a flight-like recycle/filter tank so that flight-like filters could be used, use of a different motor speed controller, and revising the purge control algorithm. The urine pretreatment process was also changed to a solid tablet form as will be used on board *ISS* (rather than liquid as for previous testing).

The operation and performance of the VCD–5 during Stage 10 are described below. A total of 1175.2 kg (2,585.3 lb) of pretreated urine/flush water and 87.2 kg (191.9 lb) of the Crew Health Care System (CHeCS) wastewater were processed by the VCD–5 during 565 hr of operation, with 1092.0 kg (2,402.5 lb) of distillate delivered to the water processor (WP) waste feed stream. The average production rate, therefore, was 1.93 kg/hr (4.25 lb/hr), somewhat less than the WRT Stage 9 rate of 2.04 kg/hr (4.50 lb/hr). The product water consistently met the water quality requirements and the VCD–5 recovered 88 percent of the pretreated urine and CHeCS wastewater.

4.4.2.1 VCD–5 Operation During WRT Stage 10. Key events during the stage 10 test are listed in table 7. Repeated events are product water conductivity high warning/alarm, sensor indications of slippage of the still drive belt, and occasional compressor outlet temperature high alarms. The high conductivity of the product water is discussed in section 4.4.2.1.6. The indication of still drive belt slippage was due to either a loose belt, Vespel® particles, or condensation on the belt. The still would come up to speed before the time limit was reached, so this did not stop the VCD–5, but could have contributed to reduced performance. On test day 35, the compressor temperature high alarm occurred when the compressor gears had worn enough to require replacement of the Vespel® gear. The cause of the compressor temperature high alarm on test day 141 has not been identified. Shutdowns occurred due to high conductivity in the product water, gear wear (prior to replacement of the Vespel® gear), and high product water pressure (on test days 45 and 128, the cause has not been specifically identified). Other, one-time, events are discussed in the following sections.

The inputs and outputs are summarized in table 8. During the first week of testing, and then daily starting on test day 28, supplemental urine was added to have a total of 7.9 kg/day (17.5 lb/day) (processing occurred every other day as a result). In addition, on each Friday 4.5 kg (10 lb) of CHeCS wastewater was added, about one-fourth of the volume of the Friday runs.

Table 7. VCD–5 key events during WRT Stage 10.

Date	Test Day	Event/Resolution
10/9/96	9	Appeared That the Drive Belt was Slipping (S4 was Low)
10/11/96	11	Product Water Pressure High Alarm, Due to Facility Valve Inadvertently Left Open When Working on a Flow Meter, the Valve was Closed
10/12/96	12	Shutdown, Restarted After a Few Seconds
10/19/97	19	Supplemental Urine Added
10/24/96	24	K1 High Alarm >Shutdown Overnight, Restarted the Next Morning
10/28/97	28	Beginning of Regular Additions of Supplemental Urine to Have a Total of 17.5 lb/day
10/30/96	30	Vespel® Particles Found in Product Water
10/31/96	31	K1 High Alarm >Shutdown, Cleaned K1 of Vespel® Particles
11/4/96	35	K1 High Warning, Disconnected K1 to Allow Time for Water to Flush the Sensor, Cleaned Vespel® Particles From V010 (pH) T1 High Alarm >Shutdown, Due to Gear Wear and Free Gas in Wastewater Inlet
11/6/96	37	Vespel® Gear Replaced
11/7/96	38	K1 High Warning, Disconnected K1, Then Reconnected
11/14/96	45	P4 (Product Water) Pressure High >Shutdown
11/15/96	46	K1 High Alarm
11/23/96	54	K1 Alarm Not Responding, Shutdown to Clear Alarm
12/2/96	58	K1 High Warning, Disconnected K1 So That Distillate Would Be Produced, Reconnected After Processing Began, No Warning Recurred
12/6/96	62	Q1 Low Alarm, Never Before Happened During Backfilling of Tank, Looks Like Valve V4 Did Not Close
12/9/96	65	A Sample Port Was Added Downstream of the Feed Tank (on Top of the Tank).
12/18/96	74	K1 High Alarm >Shutdown
12/20/96		Shutdown for Christmas/New Year's Day Holiday Break
1/6/97	76	S4 Indicates That the Still Is Slipping
1/8/96	78	S4 Indicates That the Still Is Slipping
1/21/97	91	K1 High Alarm >Shutdown
1/29/97	99	K1 High Warning
2/4/97	105	S4 Indicates That the Still Is Slipping, K1 High Warning
2/11/97	112	K1 High Warning
2/18/97	118	S4 Indicates That the Still Is Slipping
2/25/97	124	K1 High Warning
2/27/97	126	K1 High Warning
3/3/97	128	P4 Alarm, Product Water Pressure too High >Shutdown, K1 High Warning
3/4/97	129	VI01/VF01 Stuck
3/20/97	141	T1 High Alarm >Shutdown
3/21/97	142	Purge Pump Not Working >Shutdown Due to High P and T in the Still, Facility Vacuum Connected to the Vent Port
3/24/97	143	Connected Facility Vacuum to Downstream of Valve V3
3/26/97	145	Leak Through Purge Pump or V3 Suspected

Table 8. VCD–5 inputs and outputs during WRT Stage 10.

VCD–5 Inputs.

Units	Urine	Flush	Supplemental Urine	Supplemental Flush	CHeCS	Total
kg	731.70	181.92	196.60	64.94	87.23	1,262.39
lb	1,609.74	400.22	432.52	142.87	191.90	2,777.25

VCD–5 Outputs

Units	Brine	Samples	Product Distillate	Total
kg	133.52	26.90	1,092.03	1,252.45
lb	293.75	59.19	2,402.46	2,755.40

4.4.2.1.1 Software/Firmware Changes. The computer algorithm that controls the purge pump was modified prior to beginning stage 10 to correct the following problems with the purge pump/valve control:

1. During transition from *normal* to *standby,* the purge valve closed when it was supposed to remain open.
2. Instead of having a 10 min purge cycle, the purge pump remained on continuously.

These problems were due to software errors and required new Erasable Programmable Read Only Memory (EPROM's). The desired sequence is that at startup the pump housings are purged for 10 min, then the still is purged. The controller checks the pressure in the evaporator and stops when the pressure is reduced to the vapor pressure (determined by a curve based on the vapor pressure at the current temperature), then purges for 2 min every 10 min.

As noncondensable gases build up in the still, one effect is that the current draw of the compressor increases. When the current reaches 11A, a purge is supposed to be initiated, however, the software had not been changed to ensure that this would happen. New EPROM's corrected this also, prior to beginning Stage 10.

4.4.2.1.2 Motor Speed Controller. Prior to beginning the test, it was also found that the rotation speed of the still was about 63 rpm rather than the desired 180 rpm. This was due to the controller telling the motor that no more speed was needed, not because the belt was slipping, although slippage may have occurred as well. The compressor was not coming up to speed either, but the speed signal was misinterpreted due to a software error. The motor and controller signals were, apparently, scaled improperly such that the motor would never reach the desired speed. The motor speed controller was replaced prior to Stage 10 and the new motor controller worked properly.

4.4.2.1.3 Vespel® Gear Replacement. Vespel® particles began appearing in the product water on test day 29, indicating degradation of the Vespel® gear. When the still was disassembled on test day 37 to replace the gear, rust was found on the hub where L1 feeds through, apparently from the three locking rings behind the hub. Yellow crystalline deposits were found on the separator plate between the evaporator spokes. Vespel® dust was "everywhere", including coating the drive belt. The old gear showed less wear than expected (there were no chips or broken teeth) but the backlash was 0.279 to 0.533 mm (0.011 to 0.021 in.). With the new Vespel® gear the backlash was 0.102 to 0.127 mm (0.004 to 0.005 in.). It is estimated that the Vespel® gear had about 8,000 hr of operation time, including 7,300 hr of continuous operation at LSI and 700 hr of start and stop operation at MSFC (WRT Stages 9 and 10).

A filter was added to the product water line to monitor the presence of Vespel® particles in the water. Over time, after replacement of the gear, the amount of Vespel® particles in the water diminished as residual particles were removed and as "wearing in" of the new gear occurred.

4.4.2.1.4 Calculation of the Percentage of Solids in the RFTA. The criteria for determining when to clean the recycle tank and replace the filter was initially based on when the VCD software controller indicated it was time for replacing the filter, calculated by the amount of wastewater processed. As the solids concentration increases the filter becomes coated, as shown in figure 18. The amount of wastewater processed was determined by the delta of Q1 (which measures the bellows position in the supply tank) before and after a processing period. This procedure, however, does not account for wastewater added during a processing period, and so, frequently, more wastewater was processed than was indicated. One result was that the percentage of solids in the recycle tank exceeded the intended level of 25 percent solids when the tank is cleaned. The numbers shown in table 9 (see sec. 4.4.2.1.8) are the CL1 sensor readings, which were below the actual values. This affects the performance, and may have contributed to a lower production rate, although this same situation existed during stage 9 testing, as well. (All other testing of the VCD at MSFC was in batch mode, which is not subject to this effect.) By manually calculating the amount of wastewater processed, to account for wastewater added during a processing cycle, the amount of solids on the filter was decreased. This procedure change was made on test day 65.

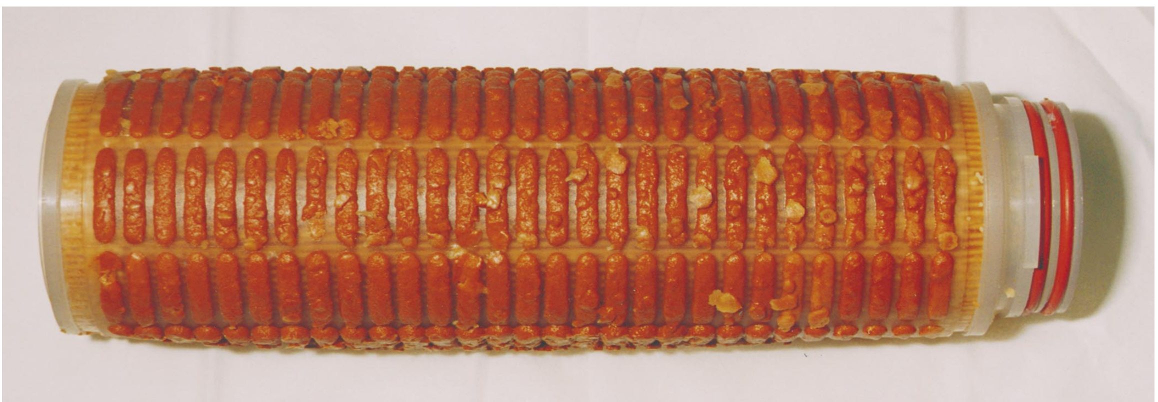

Figure 18. VCD–5 10 μm pore size filter used during WRT Stage 10.

4.4.2.1.5 High Temperatures and Pressures in the Still. As shown in figures 19 and 20, at the beginning of a processing cycle, high temperatures and pressures occurred in the still during the first 40 min before coming down to the desired ranges. The temperature was measured at the outlet of the compressor (vt1) and indicated the temperature close to the gears. The temperature spiked above the alarm setpoint of 93 °C (200 °F) due to the excessive load on the compressor and/or inadequate cooling of the gears. The pressure was measured in the condenser (vp1) and reached about 60 mmHg. These same conditions occurred during previous testing (see the Stage 9 report [8]) and were attributed to air in the wastewater tank collecting at the top of the tank, where the outlet is located, and being injected into the still (in microgravity the air would likely be more evenly distributed throughout the liquid). Therefore, until liquid was injected into the still, no evaporative cooling would occur. The condition of the compressor gears was also found to be a factor. After test day 37, when the Vespel® gear was replaced, the temperature and pressure spikes were reduced considerably, to within the desired ranges (as shown in figures 21 and 22). After test day 65, when a sample port (number 19) was added to the top of the feed tank, the temperatures and pressures at startup were reduced further (as shown in figures 23 and 24). In the process of collecting samples of the feed mixture, at the beginning of each processing cycle, the air was purged from the supply line. The transition time required to reach normal operating conditions was reduced from over 3 hr to under 2 hr, due to replacing the Vespel® gear and purging air prior to a processing run.

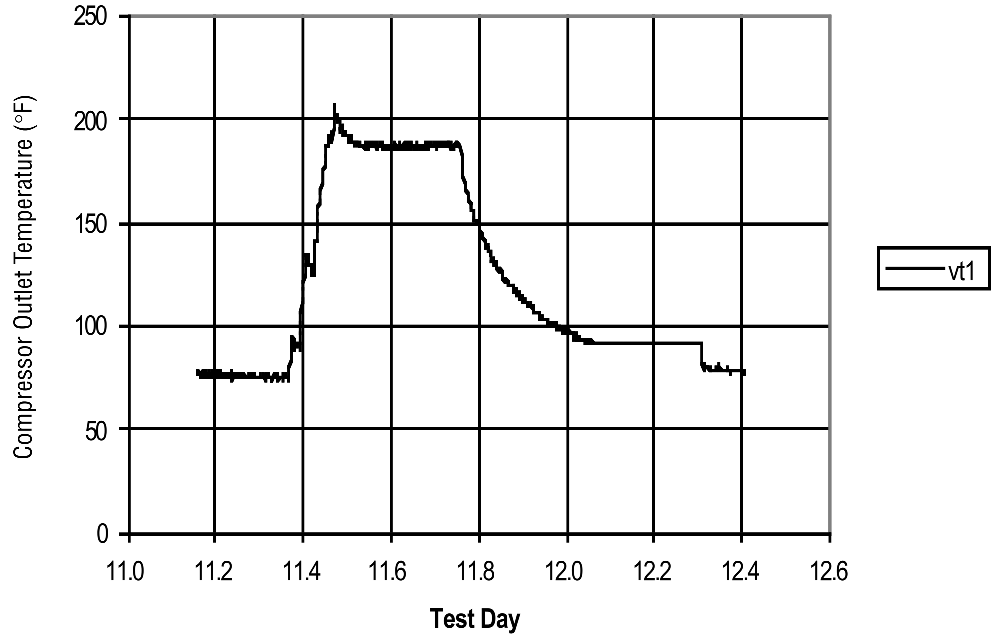

Figure 19. VCD–5 compressor outlet temperature (WRT Stage 10 test days 11 and 12).

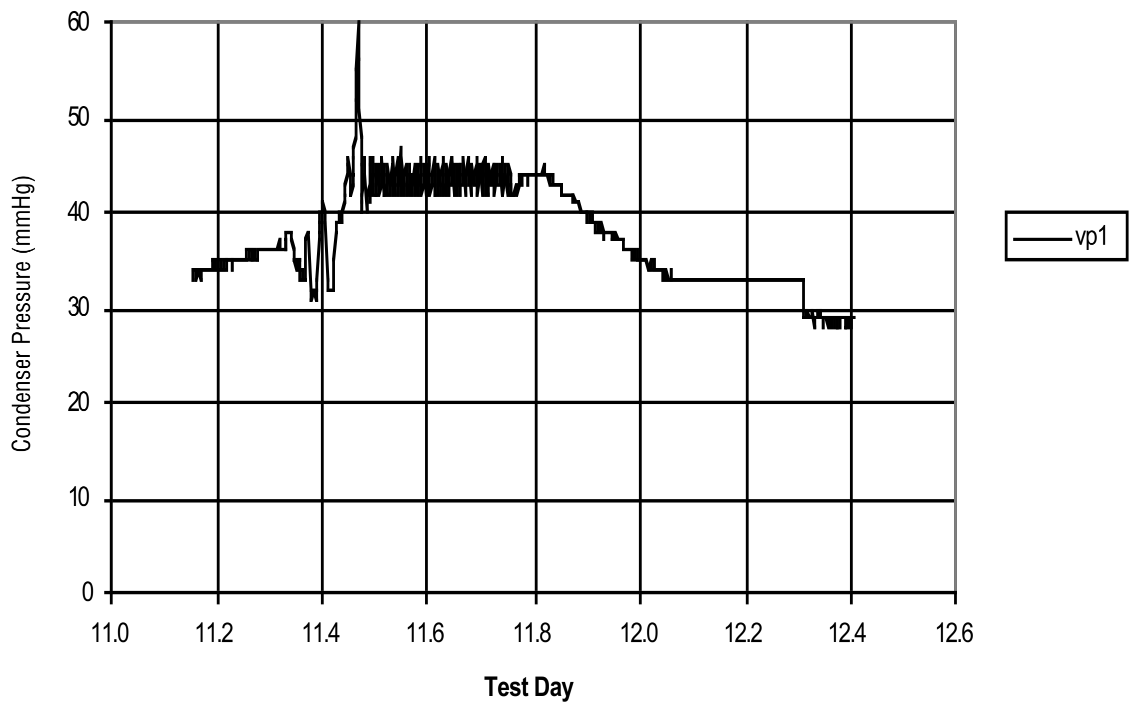

Figure 20. VCD–5 condenser pressure (WRT Stage 10 test days 11 and 12).

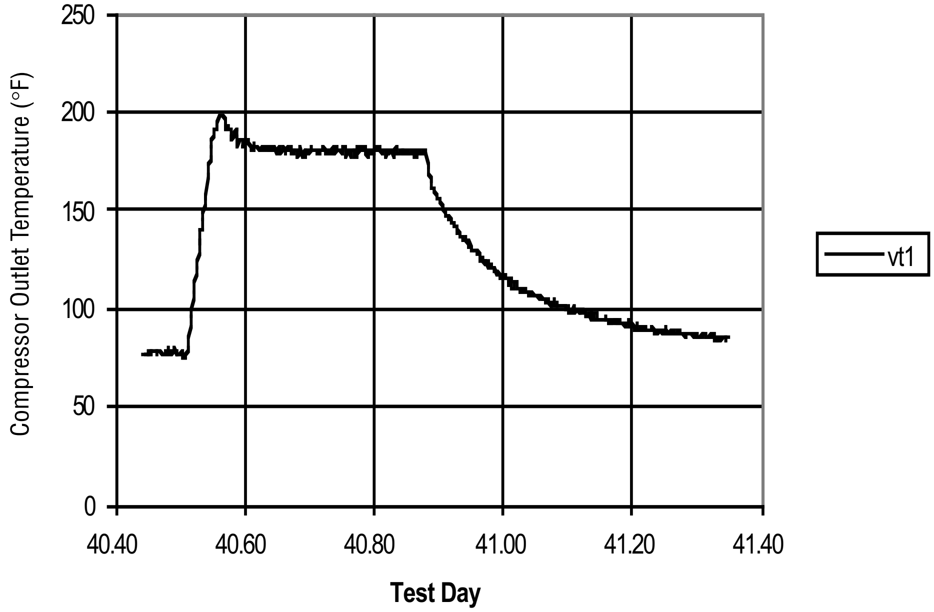

Figure 21. VCD–5 compressor outlet temperature (WRT Stage 10 test days 40 and 41).

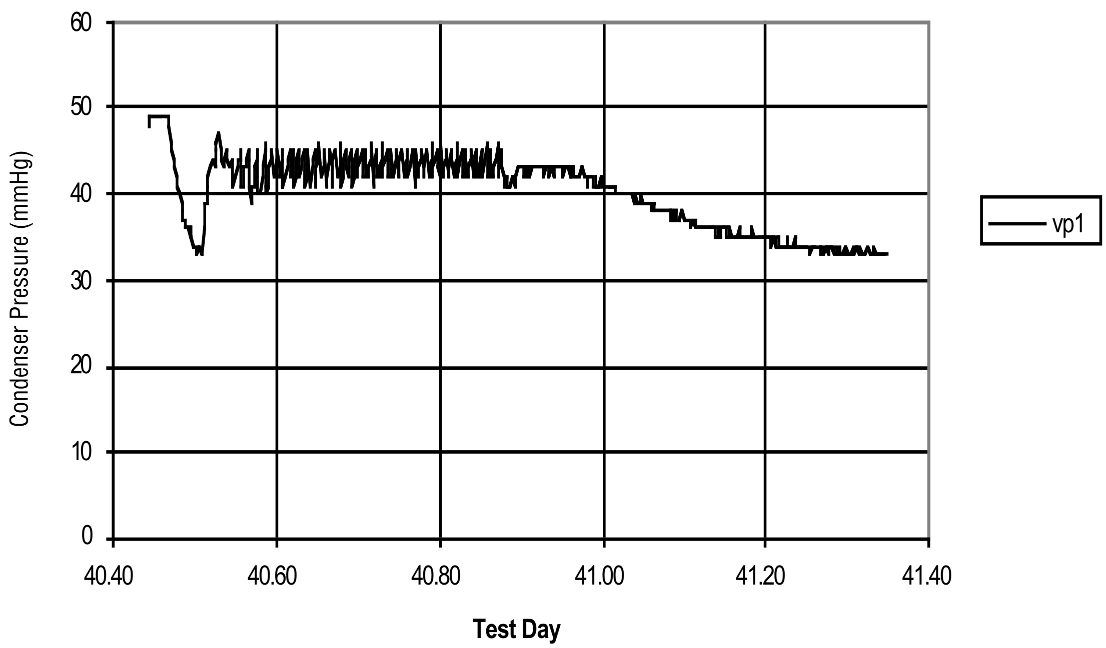

Figure 22. VCD–5 condenser pressure (WRT Stage 10 test days 40 and 41).

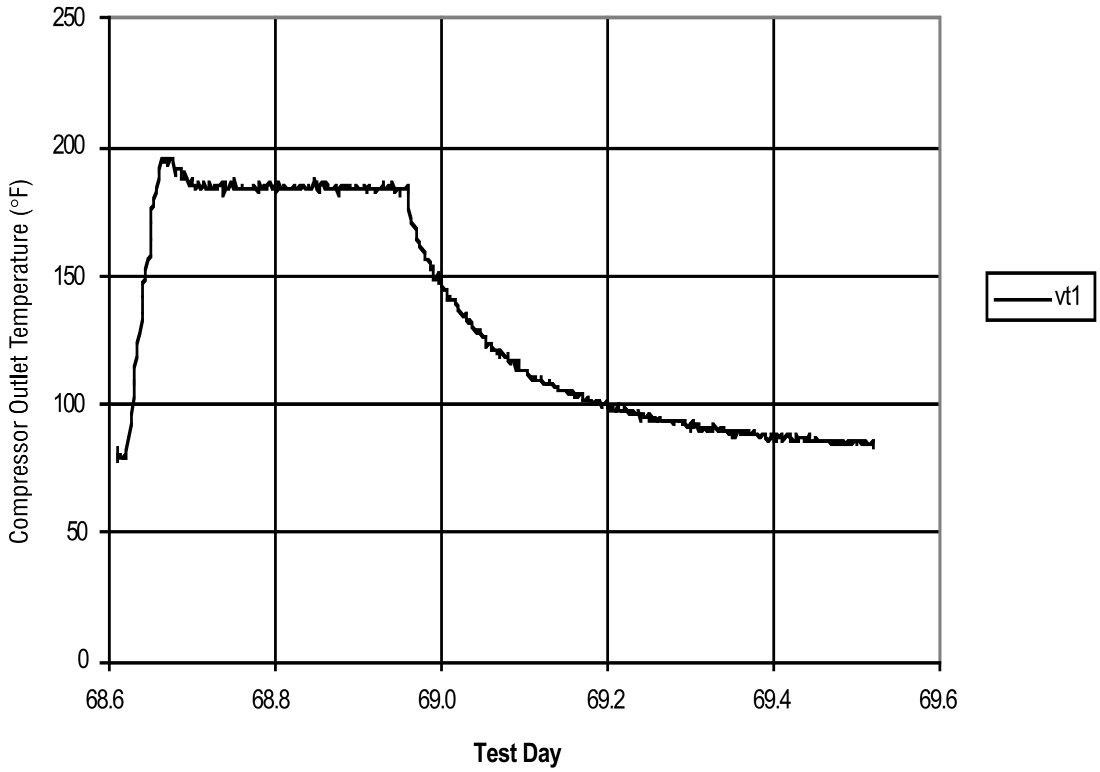

Figure 23. VCD–5 compressor outlet temperature (WRT Stage 10 test days 68 and 69).

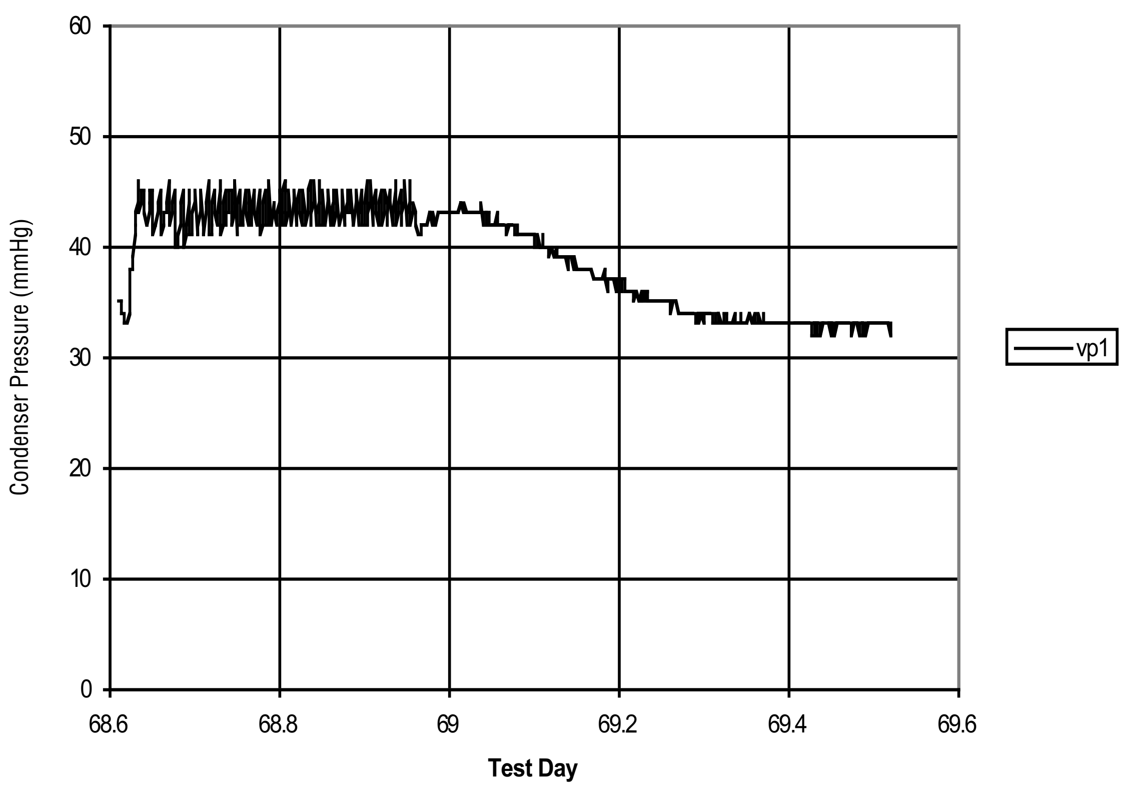

Figure 24. VCD–5 condenser pressure (WRT stage 10 test days 68 and 69).

Figure 25 shows the condenser temperature (vt4) calculated from the operating pressure (by the VCD software based on saturated steam correlations) during nominal processing of a batch of pretreated urine. This is typical of the operating temperature curves for the VCD–5.

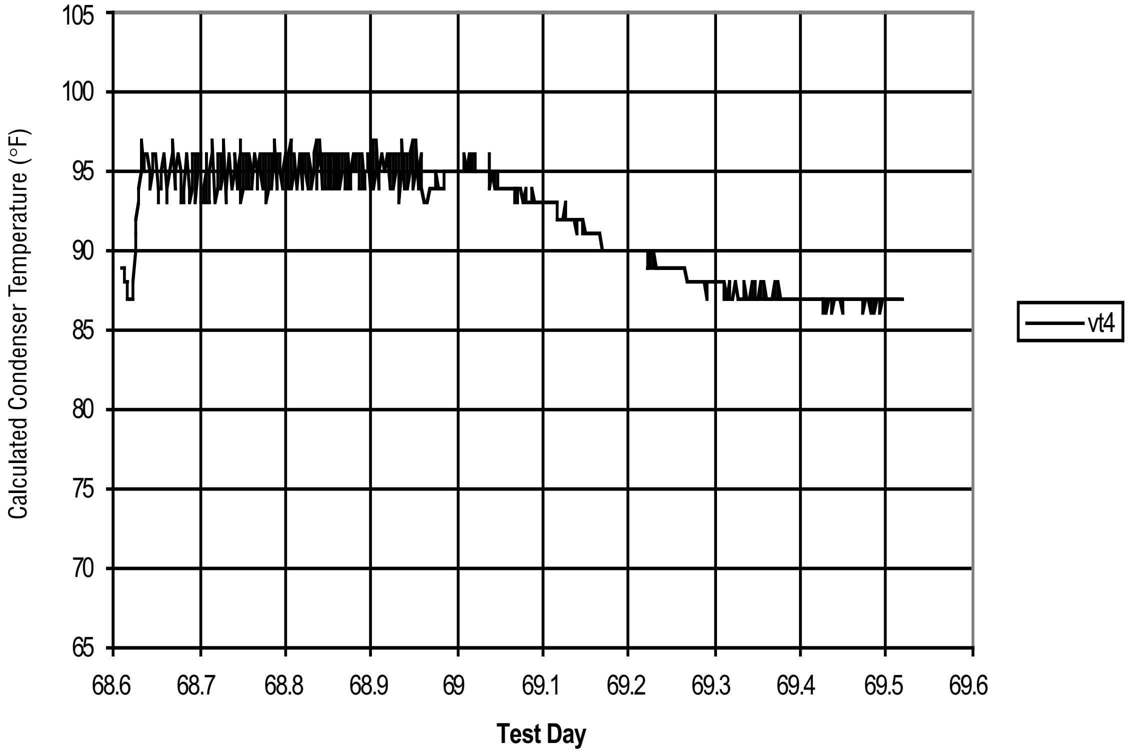

Figure 25. VCD–5 calculated condenser temperature (WRT Stage 10 test days 68 and 69).

4.4.2.1.6 High Conductivity Alarms. During the transition from *standby* to *normal*, reprocessing of the product water occurs while the pumps and motors are coming up to speed. Then after the fluids pump is up to speed, the product water conductivity sensor (K1) checks the conductivity of the product water and if it meets specification then the reprocessing valve (V2) switches to deliver product water, and within 1 to 2 min the transition to *normal* is completed.

If the water does not meet the specification when the transition to *normal* occurs then a high conductivity warning is initiated and V2 switches back to reprocessing for up to 15 min. Within the 15 min period, if the conductivity of the water drops below 120 µmho/cm for 2 min then V2 cycles to product. If the conductivity is still high at the end of the 15 min period then an alarm is initiated and the VCD shuts down.

Repeatedly, throughout much of the test, at the beginning of a processing cycle K1 would indicate high conductivity (>250 µmho/cm) which could lead to shutdown. In order to prevent shutdown, if the water was still above specification near the end of the 15 min period, K1 was disconnected (which sends a reading of 0) which caused V2 to cycle to product. K1 was then reconnected within a few sec. Upon reconnection, K1 indicated high conductivity and V2 cycled back to reprocessing for another

15 min period. This procedure was repeated until the conductivity stayed within specification, which could require several repetitions. If K1 had not been disconnected, and the VCD shutdown and restarted, after several restarts the conductivity would be within specification. Disconnecting K1 was a time-saving procedure which had the same result.

High conductivity was not detected later in a cycle and samples of the product water were well within specification (with one exception on test day 35, as shown in figure 26 which also shows the pH of the product water samples). One effect would be a reduction of the production rate, and this may have contributed to having a lower average rate than for Stage 9. The primary cause of this condition was later found to be due to leakage of brine into the fluid pump housing (see section 4.4.1.1).

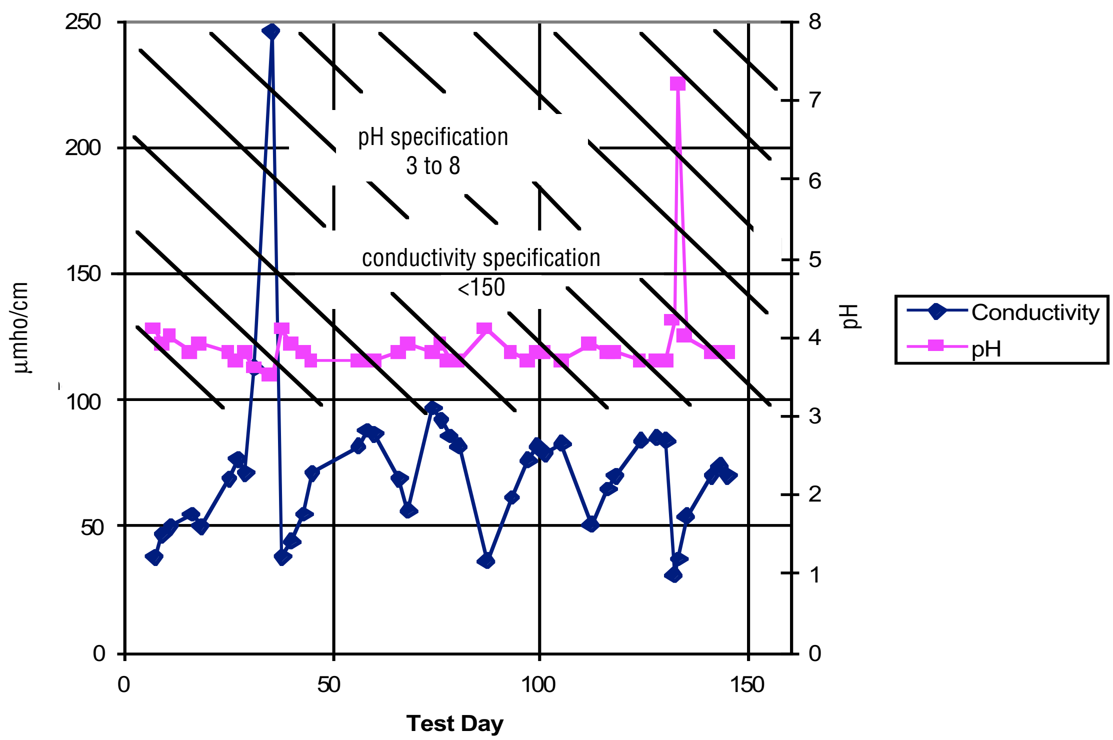

Figure 26. VCD–5 product water conductivity and pH.

4.4.2.1.7 Purge Pump Failure. Near the end of the test (test day 142) the purge pump failed, leading to high temperatures and pressures in the still. To enable continued operation, a facility vacuum source was connected to the vent port (as shown schematically in figure 35 for the VCD–5A). After completion of the test, the purge pump was disassembled but no apparent mechanical failure was found. When the pump was reassembled and checked, it worked as intended. It is thought that a seal began leaking and that during reassembly it was seated properly.

4.4.2.1.8 Recycle/Filter Tank. After cleaning of the recycle tank and replacement of the filter, it takes two cycles of the wastewater supply tank (fill and drain) to fill the recycle tank before processing is initiated. The recycle/filter tank cleanings and filter replacements are listed in table 9. The filters used during WRT Stage 10 were: single 10 µm pore size Osmonics Flotrex pleated filter (flight-like) used initially, single 30 µm pleated filter (used two times), and double 25 µm spiral wound filter. Initially the 10 µm filters were used, until December 5, 1996 when a 30 µm filter was installed in order to determine whether there was a significant difference in performance of the different filters. For the last processing cycle, two 25 µm filters were used (the same type as used on all previous VCD testing at MSFC prior to stage 10), also to compare the performance. No significant difference in water processing rate or quality was apparent. The conditions of the filters showed variation, but this was true even when the same type filters were used. The reasons for this variation may be related to different amounts of water processed (related to the method for calculating percentage of solids in the recycle tank, see section 4.4.2.1.4) as well as the different types of filters used. Further testing is needed to determine the reasons for this variability and whether this could pose a problem.

Table 9. VCD–5 recycle/filter tank cleaning/filter replacement during WRT Stage 10.

Date Removed	Test Day	Condition	Filter	Notes
9/30/96	0	New	10 µm Osmonics Flowtrex	Start of test on 10/1/96
11/4/96	35	bottom 3/4 of filter coated with thick brown-red brine, bottom of tank with thick white/yellow sludge	10 µm	Stopped due to gear wear, not solids buildup in the brine.
11/19/96	50	12.7% CL1, tank fluid was dark and the filter was dark (no solids on filter)	not replaced	Removed for inspection and addition of a ΔP sensor and an inlet P transducer, not cleaned, no filter replacement
12/5/96	61	24.7% CL1, larger crystals were found in the brine than on 11/4	10 µm	Replaced with 30 µm, tank filling failed, drained tank and reevacuated, V4 did not close which drained the feed tank too low, resulting in Q1 low alarm
1/14/97	84	22.2% CL1, similar condition but not as bad. All slots on plastic sleeve filled with solids.	30 µm	replacement based on throughput, not Q3
2/7/97	108	24.93% CL1, no crystals on filter mount, white crystals on filter	30 µm	replaced with two 25 µm filters to compare buildup of solids
3/6/97	131	21.4% CL1, light tan tint, some small formations of light brown crystals, no thick brown solids, white solids on bottom of tank	25 µm (two filters)	replaced with original single element pleated 10 µm filter

4.4.2.2 VCD–5 Performance. The VCD–5 production rate is shown in figure 27, which also shows when the recycle tank cleanings and filter replacements occurred during the test and the type of filter used. Tank cleaning and filter replacement occurred when the throughput of urine to the VCD–5 reached approximately 182 kg (400 lb). The VCD–5 averaged 1.93 kg/hr (4.25 lb/hr) during the test, below the specified processing rate of 2.04 kg/hr (4.5 lb/hr) for the *ISS*, which was achieved during Stage 9 testing. The production rates were determined by dividing the amount of water processed in a batch by the number of hours the VCD–5 was in operation. The duration of operation includes the transition periods from *standby* to *normal* operation (which may take an hour or more) and from *normal* to *standby* (which takes from 5 to 10 min), and periods of reprocessing. The production rate decreased over time as the solids concentration increased in the recycle loop. The rate increased each time the recycle tank was cleaned. The VCD–5 recovered about 88 percent of the pretreated urine and CHeCS wastewater. This recovery rate is similar to previous testing conducted with the VCD–5. Differences in water recovery are generally due to the timing of the cleaning of the recycle/filter tank.

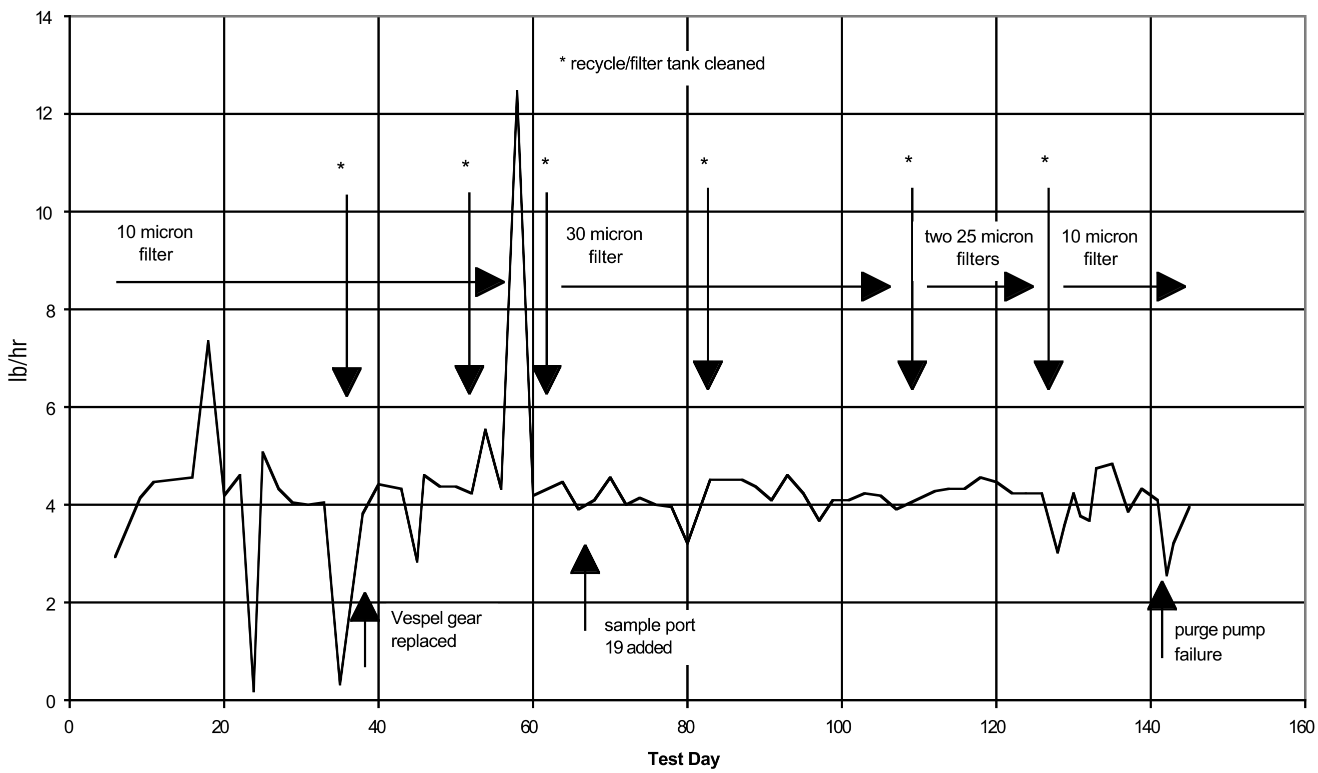

Figure 27. VCD–5 product water production rate during WRT Stage 10.

4.4.2.3 VCD–5 Product Water Quality. The water quality specifications and average water quality data for the VCD–5 distillate are shown in table 10. The TOC, total inorganic carbon (TIC), and total carbon are graphed in figure 28. In general, the water quality was considered nominal for the VCD–5, and was well within the specified level. The only exception was on test day 35 when the TOC reached 105 mg/L. The reason for this may be related to the mechanical problems experienced on that day due to wear of the Vespel® gear. As shown in figure 26, the pH and conductivity are well within specification, with the only exception on test day 35 when the conductivity reached 246 µmho/cm. On test day 133 the pH showed a spike to 7.2. The reason for this has not been determined. No differences in water quality were attributed to adding CHeCS water or to the urine pretreatment tablets, although the average conductivity was about 12 µmho/cm higher than for Stage 9, and higher than the 40 to 60 µmho/cm (occasionally above 70) during life testing in 1993 and 1994. Even so, the average conductivity was well below the *ISS* specification of 150 µmho/cm maximum.

Table 10. VCD–5 product water quality during WRT stage 10.

Parameter	Specification	Units	Average for Stage 10	# of Samples
Conductivity	<150	µmho/cm	72.10	41
pH	3 to 8	pH	3.90	41
Total Organic Carbon	<50	mg/L	23.49	41

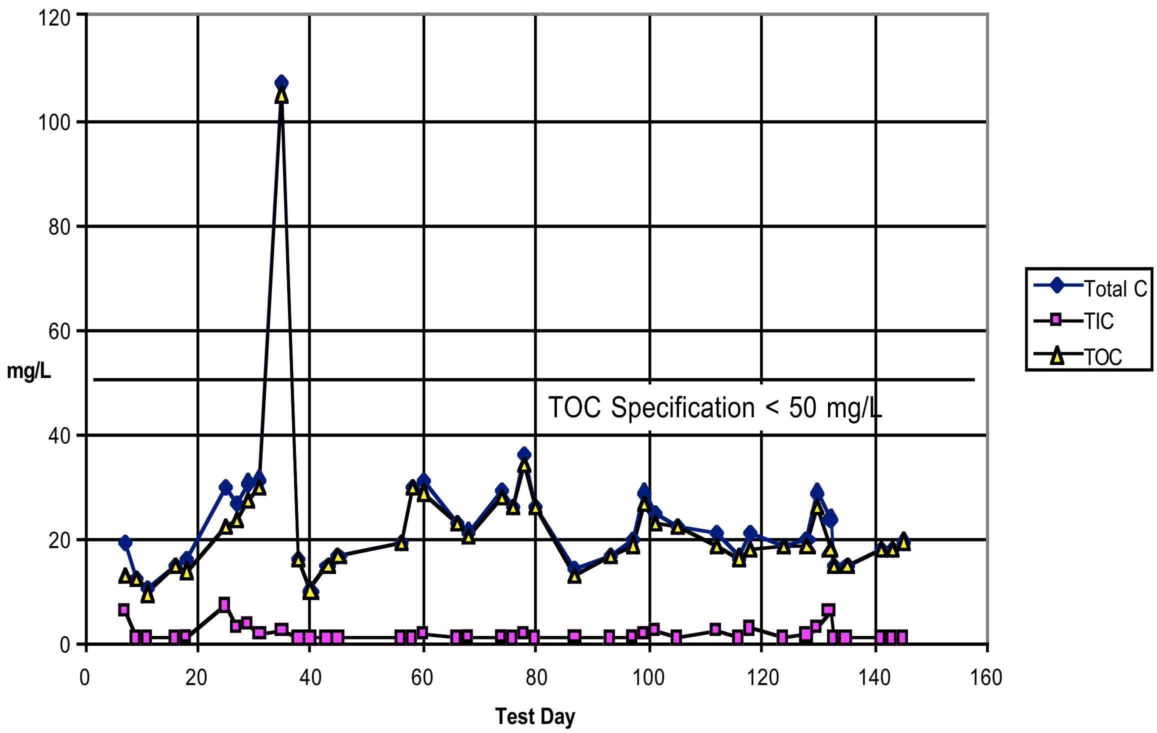

Figure 28. VCD–5 product water carbon composition during WRT Stage 10.

4.4.2.4 VCD–5 Conclusions and Recommendations from the WRT Stage 10. Overall, the quality of the product water was well within the specified levels, increasing confidence in the ability of the VCD to produce water meeting the required specifications. The production rate (1.93 kg/hr, 4.25 lb/hr) was somewhat below the specified rate (2.04 kg/hr, 4.50 lb/hr), but the reasons for this may be related to the shutdowns that occurred during processing cycles and additional reprocessing due to high conductivity readings. The shutdowns were caused by other subsystems being tested (the WP), or by VCD–5 anomalies such as the Vespel® gear failure and its related problems. The variation in condition of the filters needs further investigation to determine the reasons for this variability and whether this could pose a problem during flight operations.

4.5 VCD–5A Testing

The VCD–5A life test began on January 12, 1993 and ran until November 9, 1995 (612 test days) with additional testing (Purge Gas Test) after some repairs were made, until April 24, 1996, for a total of 665 test days. A Gantt chart of the VCD–5A operation is shown in figure 29. Plots of typical operating conditions for the compressor temperature (T1), compressor motor current (I1), and condenser pressure (P1) are shown in figures 30, 31, and 32, respectively. The total mass of wastewater/urine processed was 5,198 kg (11,449 lb) until November 9, 1995. The overall average production rate was, therefore, 1.76 kg/hr (3.87 lb/hr) for 2,960 hours in *normal*, through November 9, 1995. The quality of the product water (measured by conductivity as shown in figure 33) was well below the specified limit (150 µmho/cm) except for a few momentary spikes. The conductivity increased until the recycle filter tank was replaced, when it would drop to about 25 µmho/cm. The composition of the product water and the brine are listed in table 11.

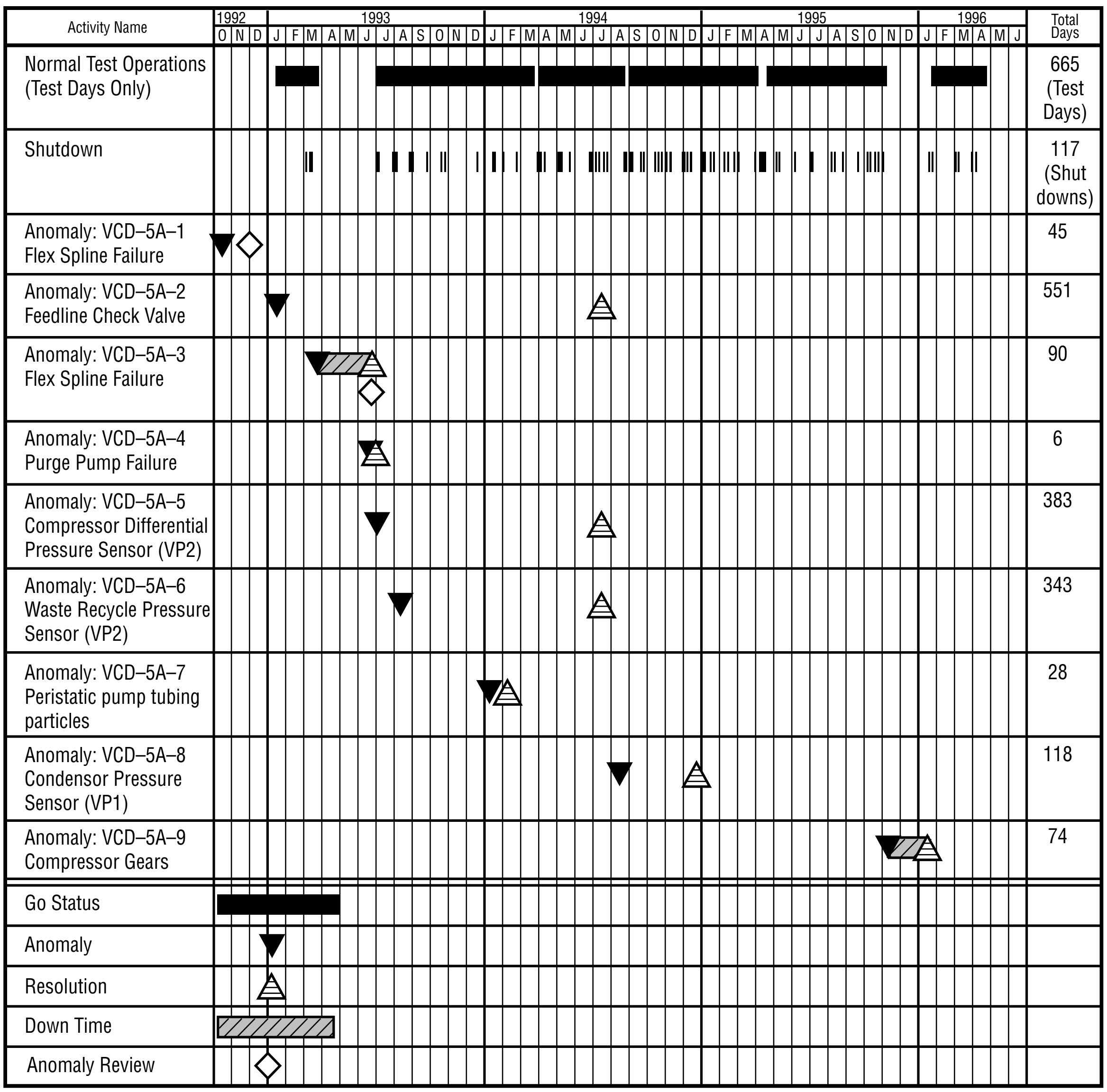

Figure 29. Gantt chart of VCD–5A operation.

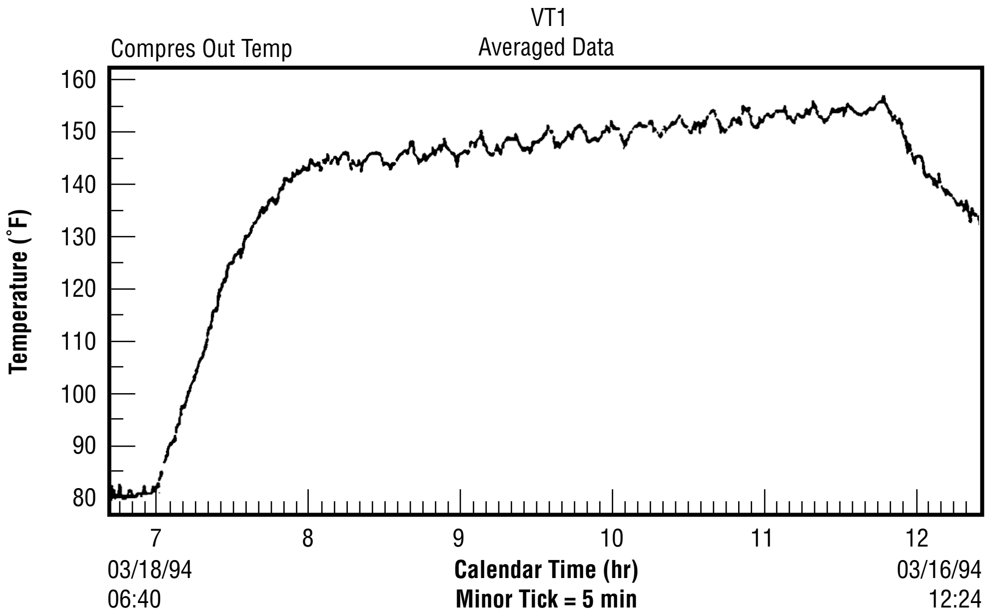

Figure 30. VCD–5A typical compressor temperatures (T1).

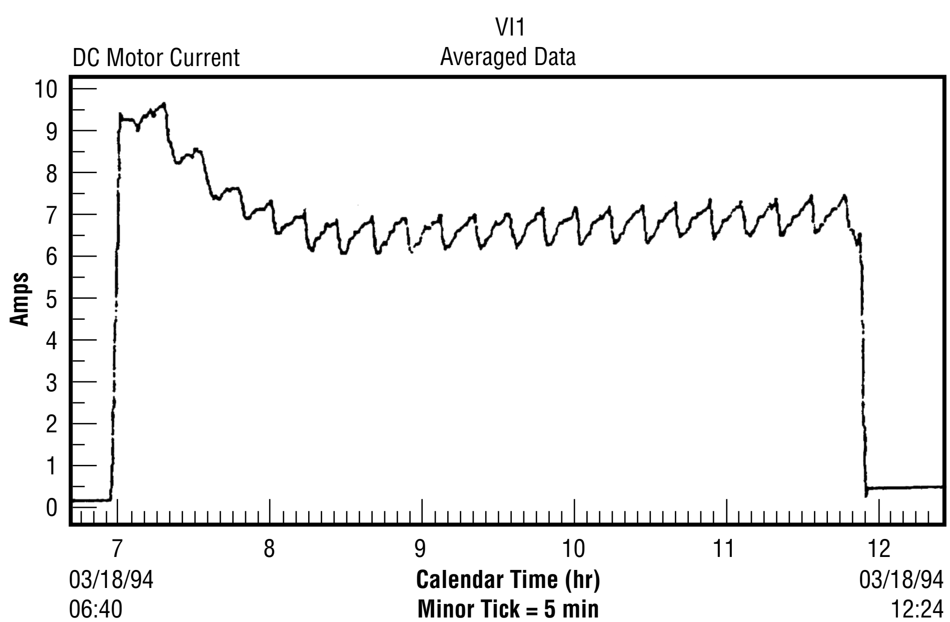

Figure 31. VCD–5A typical motor current (I1).

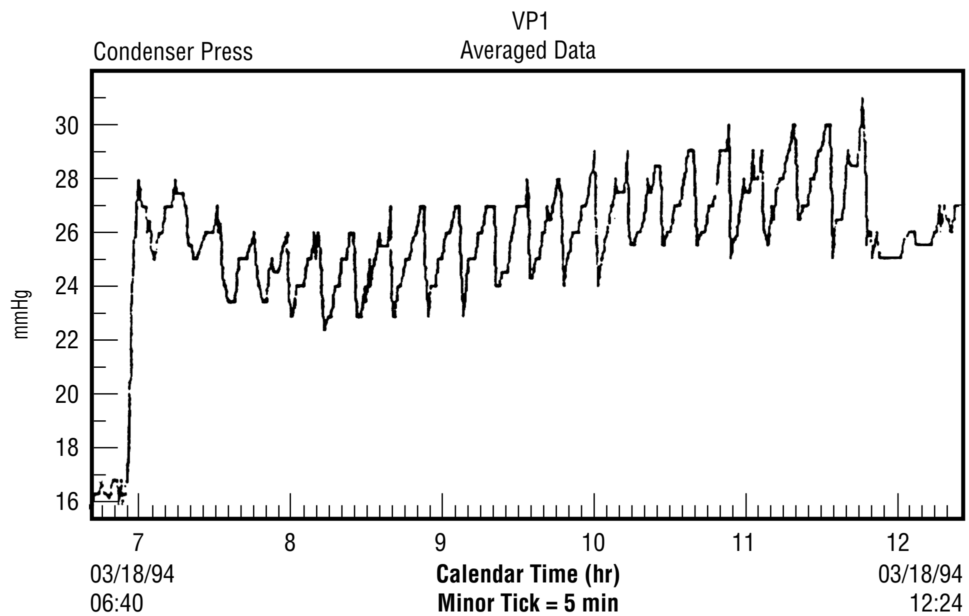

Figure 32. VCD–5A typical condenser pressures (P1).

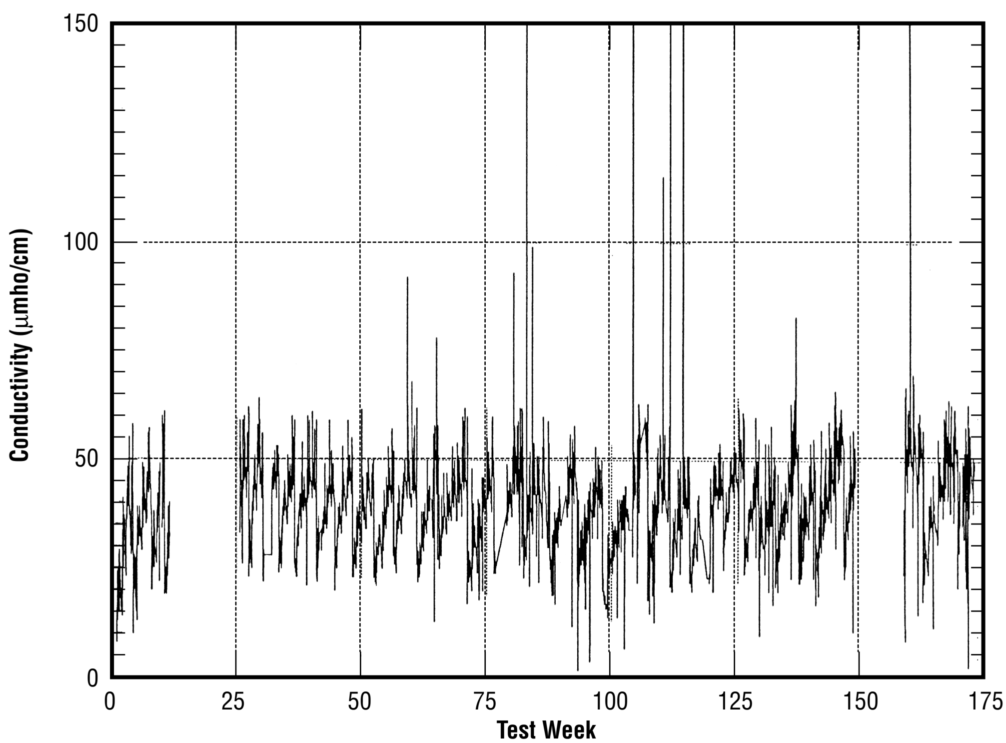

Figure 33. VCD–5A product water conductivity.

Table 11. VCD–5A product water and brine compositions.

Characteristic	Units \ Date	87	92	97	104	106	111	116	121	125	130	135	140	144	149	152	162	167
Test Day / Date			30 Aug 93			20 Sep 93				18 Oct 93				15 Nov 93			13 Dec 93	
Product Water Composition																		
pH		3.8	4	3.8	3.8	4	4	3.8		4	4	3.8		4	3.9	3.8	4	3.9
conductivity	μmho/cm	70	43.4	61.6	72.4	44.4	56.9	68		41.9	50.2	62		47.2	61	64.7	44.9	55.9
turbidity	NTU	0.1	0.1	0.2	<0.1	0.2	0.4	<0.1		0.1	<0.1	0.9		<0.1	<0.1	<0.1	0.1	0.1
TOC	mg/L	22.5	13.3	18.7	24.3	14.5	19.1	19.4	17.7	19.7	13.6	16.1	18.7					
TIC	mg/L	1.11	<1.0	1.67	4.71	<1.0	2.68	2.45	<1.0	2.36	2.23	<1. 0	1.57					
TC	mg/L	24	13	20	29	15	23	22	18	22	16	16	20					
Particles:																		
0-5 μm particles	particles/mL	18.4	64.5	74.2	57	79.5	44.3	63.8	47.5	32	70.9	42.9	54.7	52.9	40.4	45.9		45.1
5.1-10 μm particles	particles/mL	2.2	10	8.86	3.52	7.95	4.78	2.9	2.92	<2.0	5.5	4.92	3.55	3.38	<2.0	3.25		2.4
10.1-40 μm particles	particles/mL	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0
40.1-100 μm particles	particles/mL	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0		<1.0
Brine composition																		
Refractive Index		1.363	1.343	1.352	1.363	1.341	1.351	1.355	1.36	1.338	1.345	1.351	1.356	1.342	1.349	1.353		1.349
Specific Gravity		1.104	1.033	1.066	1.103	1.026	1.062	1.075	1.093	1.018	1.042	1.063	1.084	1.026	1.061	1.07		1.058
Solids Conc. (BS)*	%	21.34	7.07	13.49	21.34	5.64	12.78	15.63	19.20	3.50	8.49	12.78	16.35	6.35	11.35	14.20		11.35
Solids Conc. (UJ)*	%	16.15	5.27	10.17	16.15	4.19	9.62	11.80	14.52	2.56	6.36	9.62	12.34	4.73	8.54	10.71		8.54
Solids Conc. (UP)*	%	19.29	6.70	12.37	19.29	5.44	11.74	14.26	17.40	3.56	7.96	11.74	14.88	6.07	10.48	13.00		10.48

Double vertical lines indicate cleaning of the recycle filter tank and replacement of the filters.
* Note: The Solids Concentration is calculated based on the refractive index and specific gravity of the brine.
Three different methods were compared to calculate the % solids:
BS = Boeing Services, UJ = Umpqua Jolly, and UP = Umpqua Putman.

The recycle filter replacements and the amounts of water processed through each filter are shown in table 12 and plotted in figure 34. The average lifetime of the filters was 20.3 days of operation. The duration of operation of the VCD–5A through November 9, 1995 was:

Total hours powered	21,650
Hours in Shutdown	816
Hours in Normal	2,960
Hours in Standby	17,027
Hours in Transition	847
Hours on the still motor	3,107
Hours on the fluids pump	3,076
Hours on the purge pump	1,285

An additional 459 kg (1,011 lb) of wastewater was processed through April 24, 1996 (including the Purge Gas Test).

Table 12. VCD–5A wastewater processed between filter replacements.

Date	Test Day	Elapsed Days	Wastewater Processed (kg)	Wastewater Processed (lb)
2/4/93	16	16	161.90	356.60
2/26/93	32	16	165.08	363.62
3/18/93	45	13	147.40	324.66
7/15/93	59	14	147.36	324.58
8/4/93	73	14	174.35	384.03
8/25/93	89	16	167.23	368.35
9/17/93	104	15	160.17	352.79
10/18/93	124	20	168.38	370.88
11/10/93	142	18	163.59	360.32
12/7/93	157	15	167.88	369.78
1/6/94	177	20	164.48	362.30
2/4/94	197	2	180.99	398.66
3/7/94	218	20	171.99	378.83
4/7/94	239	21	159.51	351.35
5/16/94	266	27	143.26	315.54
6/23/94	292	26	148.22	326.48
8/3/94	319	27	167.67	369.32
9/9/94	340	21	173.99	383.23
10/16/94	364	26	171.68	378.16
11/22/94	392	26	151.19	333.01
1/24/95	424	32	159.93	352.27
2/24/95	446	22	135.36	298.15
3/22/95	465	19	150.26	330.96
5/8/95	485	20	137.76	303.43
6/6/95	506	21	160.06	352.56
6/26/95	520	14	109.91	242.09
7/19/95	534	14	89.29	196.68, stopped early to use brine for ersatz testing
8/21/95	556	22	157.99	348.00
9/14/95	573	17	105.01	231.31
10/23/95	599	26	196.02	431.76

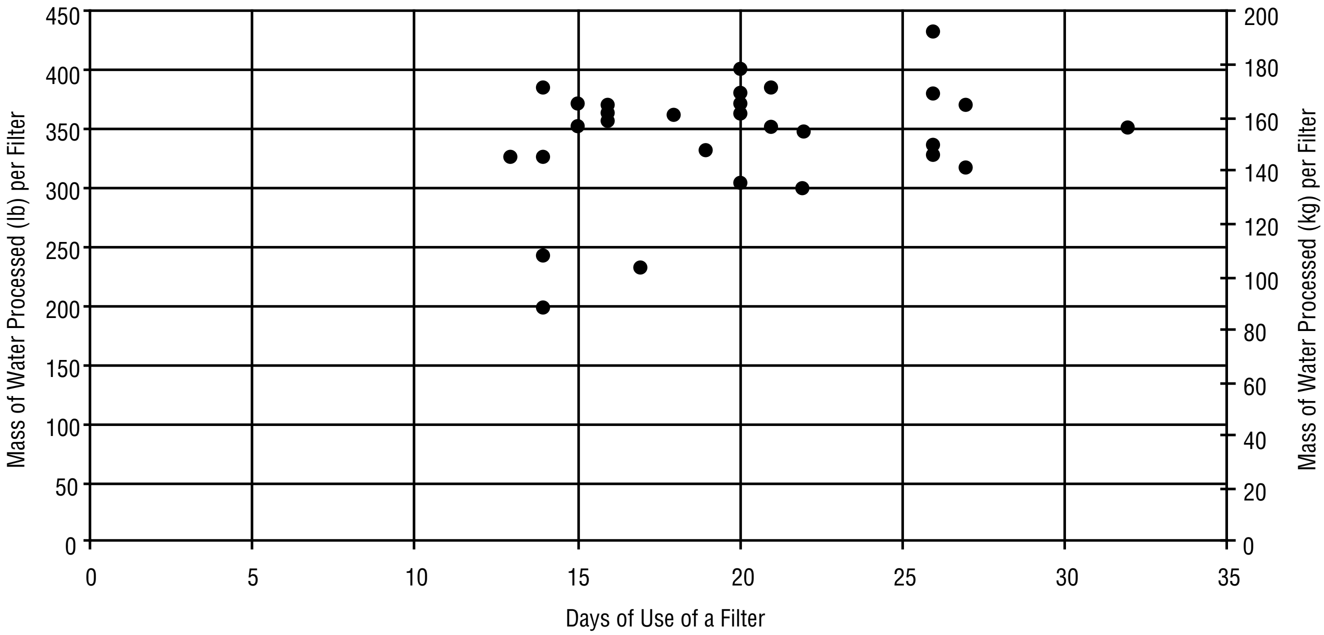

Figure 34. VCD–5A 25 µm pore size recycle filter performance.

The Purge Gas Test was conducted for three weeks to collect purge gas samples for analysis to ensure that the purge gases would not create a safety hazard during flight experiment operation. The test was halted on April 24, 1996 due to persistent high compressor motor current draws and high compressor temperatures.[11, 12] For the Purge Gas Test, the amounts of wastewater processed and the distillate produced are summarized in table 13.

4.5.1 VCD–5A Test Events and Anomalies.

The significant events and anomalies that occurred during testing of the VCD–5A are listed in table 14.

The first anomaly occurred during checkout testing of the VCD–5A at LSI when the flex spline failed in a gear speed reduction mechanism in the Harmonic Drive for the fluids pump (see fig. 10). At that time the drive had operated for about 400 hr. The failed part was analyzed at MSFC, however, a definite cause of the failure could not be determined because the failure surfaces were smeared due to the assembly operating after the component had sheared. (See the third anomaly for more information.) The drive was replaced with a new one of the same design. Previously the Harmonic Drives had operated for much longer without failure, as shown in table 2.

The second anomaly was the failure of the wastewater feed line check valve on January 14, 1993 which allowed wastewater to flow back into the external transfer tank. This did not adversely affect operation of the VCD and no immediate action was taken to replace the failed valve. The procedure was changed to include closing the manual valve at the VCD interface after transfers of wastewater from the facility supply.

Table 13. Purge gas test wastewater processing.

Test Day	1 Batch 1	1 Batch 2	2	3	4	5	6	7	8	9	10	11	12	13	Total
Urine Processed kg (lb)	12.11 (26.68)	12.21 (26.90)	20.22 (44.54)	25.03 (55.13)	11.71 (25.79)	16.91 (37.25)	12.31 (27.12)	10.31 (22.71)	9.11 (20.06)	6.29 (13.85)	5.61 (12.35)	6.01 (13.23)	5.71 (12.57)	5.91 (13.01)	159.44 (351.19)
Distillate Produced kg (lb)	12.55 (27.65)	11.37 (25.05)	18.89 (41.60)	23.70 (52.20)	10.79 (23.77)	15.89 (35.00)	11.42 (25.16)	9.53 (20.99)	7.97 (17.56)	6.17 (13.64)	5.08 (11.20)	5.49 (12.10)	5.06 (11.14)	5.42 (11.93)	149.36 (328.99)
% Recovery	103.6	93.1	93.4	94.7	92.2	94.0	92.8	92.4	87.5	98.5	90.7	91.5	88.6	91.7	93.7

Table 14. VCD–5A significant events and anomalies.

Bold indicates that a flight-like component is affected

Anomaly Number	Event/Anomaly Description	Date Occurred	Actionee	Date Closed Out	Action to Resolve Anomaly
VCD-5A-1	Fluids pump stopped due to harmonic drive failure.	10/20/92	Hutchens, Long, Salyer	12/17/92	Harmonic drive replaced. Cause not determined.
	Test started	1/12/93			
VCD-5A-2	Feed line check valve allows back flow into the external transfer tank.	1/14/93	Hutchens, Long, Salyer	7/19/94	Procedure change to close valve after wastewater transfer.
VCD-5A-3	Harmonic drive failure.	3/30/93	Hutchens, Long, Salyer	6/24/93	Determined misalignment caused failure.
VCD-5A-4	Purge pump failure.	6/25/93	Hutchens, Long, Salyer	7/1/93	Failed electronics in the signal conditioner were replaced.
VCD-5A-5	Compressor differential pressure sensor (P2) failure.	7/2/93	Hutchens, Long, Salyer	7/9/93	No action required since the sensor is not critical to data evaluation and is not included in the flight configuration.
VCD-5A-6	Waste recycle pressure sensor (P3) failure.	8/9/93	Hutchens, Long, Salyer	7/19/94	Flight-like sensor installed. New material resistant to corrosive environment that caused initial failure.
VCD-5A-7	Peristaltic purge pump tubing particles.	1/11/94	Hutchens, Long, Salyer	2/8/94	An inspection will be made periodically to monitor buildup of material.
VCD-5A-8	Condenser pressure sensor (VP1) failure.	8/26/94	Hutchens, Long, Salyer	12/21/94	Replaced with sensor made of Hastelloy C.
VCD-5A-9	High T1, high T2, high K1, and water coming out purge line. (Compressor gears worn out after 4831 hours of operation.)	11/9/95	Wieland, Long, Salyer	1/19/96	Replaced compressor gears and the drive o-ring.
	Facility vacuum used to assist the purge pump during Purge Gas Testing.				
VCD-5A-10	Compressor and still will not rotate.	6/27/96	Wieland, Long, Salyer	7/31/97	Compressor and still bearings rebuilt in-house by MSFC personnel.

The third anomaly was another failure of the fluids pump, after 51 days of testing at 362 hr of operation. The failure was similar to that which occurred during checkout at LSI. A flex spline in the Harmonic Drive of the fluids pump failed in both cases. The exhaustive 3-month investigation which followed determined that the failures resulted from a slight horizontal misalignment (0.127 mm (0.005 in.)) introduced into the pump drive shaft during its assembly at the hardware supplier. The manufacturer (Harmonic Drive Technologies) said that misalignment of the spline could overstress it and lead to fatigue failure. The potential for this problem may have been introduced into the pump during retrofit at the hardware vendor (to support the drive shaft at both ends, see sec. 2.3.2 about the retrofit), since during previous testing when the pump drive shaft was a cantilever design the Harmonic Drive operated for a much longer period of time. The vendor has implemented use of a new alignment jig during hardware assembly to ensure proper alignment. This jig will be used for flight hardware assembly. The pump was sent back to the supplier, the part replaced, and the misalignment corrected. Testing resumed on June 25, 1993, but the purge pump did not receive power, due to the fourth anomaly.

The fourth anomaly was failure of the purge pump electronics. This problem was traced to a failed power converter and capacitor on the purge pump controller card. These items were replaced and testing resumed on July 2, 1993. This failure did not affect any flight-like components.

The fifth anomaly occurred when the VCD–5A was restarted on July 2, 1993 and the compressor differential pressure sensor (P2) was nonfunctional. No actions were taken since the P2 sensor is not critical to data evaluation and is not included in the flight configuration.

The sixth anomaly was failure of the waste recycle pressure sensor (P3) on August 9, 1993. This sensor is flight-like in function (although the flight sensor will be somewhat different). LSI provided a temporary replacement sensor so the failed sensor could be analyzed. The temporary sensor was installed on August 30, 1993. Even without the P3 sensor, system backup features would allow operation of the VCD–5A.

The seventh anomaly was related to the Norprene® tubing used in the peristaltic purge pump. This pump uses the same tubing as the fluids pump although it pumps a two-phase mixture which is mostly gas. This application was found to cause spalling of the Norprene® which resulted in clogging of the gas/liquid separator with Norprene® particles. The initial resolution suggested by the hardware supplier was to add a filter downstream of the pump to prevent gas/liquid separator clogging. An inspection of the air/water separator was made every 30 days to avoid buildup of particles.

The eighth anomaly was failure of the condenser pressure sensor (P1). This sensor was replaced with a sensor made of Hastelloy C, a high nickel, molybdenum, and chromium alloy that is more resistant to corrosion.

The ninth anomaly involved high temperature alarms and liquid coming out of the purge line. The VCD–5A was deactivated until repairs could be made by LSI. The operating time on the compressor gears and the drive belt was estimated to be 4,831 hr including time before the Life Test began. The compressor gears and the centrifuge drive belt were found to be worn and were replaced. This anomaly and field service is discussed further in section 4.5.2.

The tenth anomaly was failure of the compressor and centrifuge to rotate due to worn compressor and still bearings. More torque was required than the motor generated. The compressor and still bearings were rebuilt by MSFC personnel.

Facility vacuum was used to assist the purge pump when leakage exceeded the pump capacity to adequately evacuate the pump housings and purge the condenser. The facility vacuum was connected as shown in figure 35.

During test days 613 through 665 the VCD–5A processed 460.0 kg (1,011.3 lb) of waste feed averaging about 3.6 lb/hr. The recycle filter tank was replaced on test days 626 and 651.

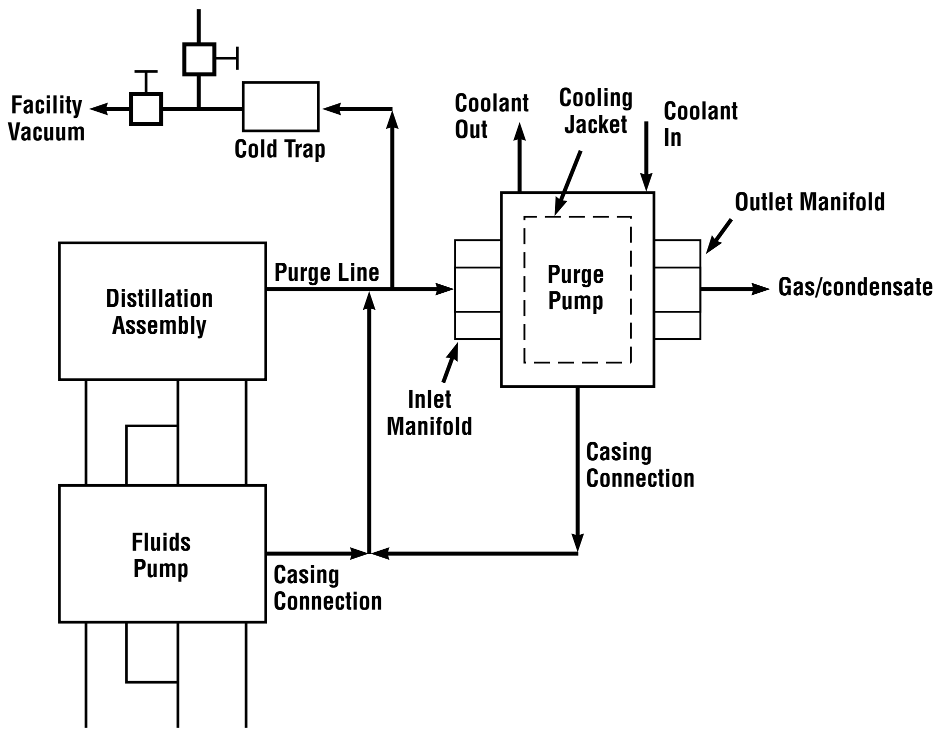

Figure 35. Facility vacuum connection to the purge and fluids pumps.

4.5.2 VCD–5A Field Service

Beginning on September 25, 1995 there were alarms and shutdowns due to high compressor temperatures. On November 9, 1995 (test day 612), testing was halted due to continued degradation even with the facility vacuum assisting, indicated by gradually increasing temperatures and current load, leading to shutdown. The symptoms at that time were:

1. Excessive noise from the compressor
2. High current loads—From the normal 6 to 7A the current increased to 10 to 12A with a startup spike up to 19A (see fig. 36)
3. Compressor temperatures increased from the normal 77 °C (170 °F) to >93 °C (200 °F). This appears to stem from the high operating pressure inside the distillation unit (see fig. 36)
4. Slippage of the centrifuge during startup was occurring more frequently.

Also, moisture was still found in the moisture trap in the facility vacuum line which indicated leakage of ambient air into the pump housing or through the pump tubing.

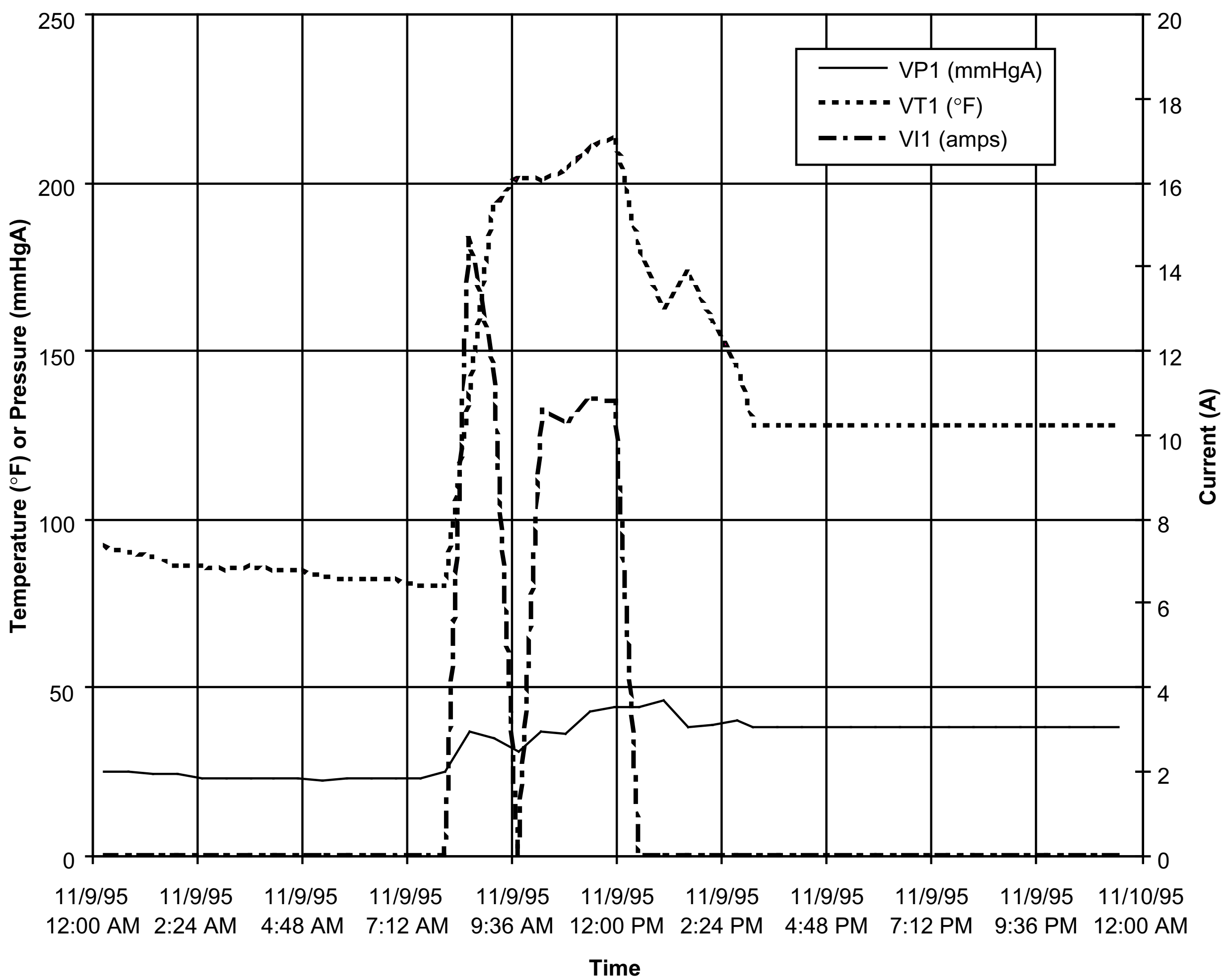

Figure 36. VCD–5A current, temperature, and pressure profiles in November 1995.

A field service was arranged to correct the problems. Due to a government furlough, the field service was postponed until January 16, 1996. Prior to disassembly, a pressure check was performed that showed no leakage into the still. The VCD–5A was then transitioned to *normal* mode. A loud noise came from the VCD–5A and the compressor motor drew excessive current (17A). The VCD–5A was switched off and disassembled.

The following conditions were noted upon disassembly of the VCD–5A:

- An O-ring seal was missing between the condenser end plate and the drum. However, there was no indication of liquid leakage, so the metal-to-metal contact apparently provided an adequate seal.
- Some slight corrosion was evident between the condenser end plate and the drum spokes, as shown in figures 37 and 38.

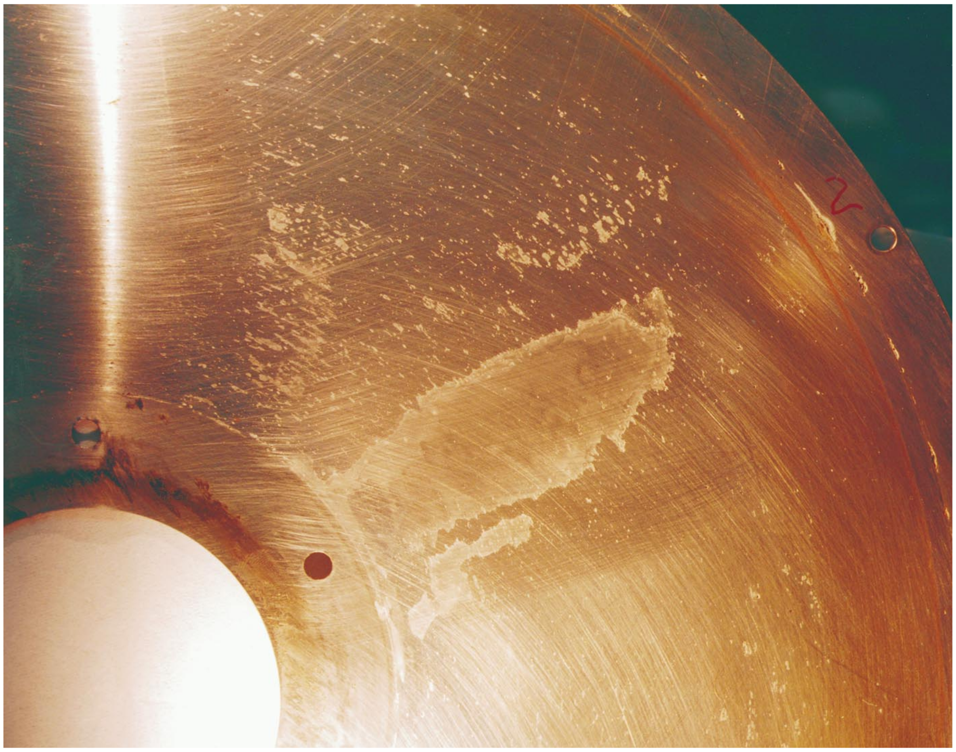

Figure 37. VCD–5A end plate showing light corrosion.

Figure 38. VCD–5A distillation drum spokes showing light corrosion.

- The wastewater injection tube had a small “blob” of solids (3.2 to 6.4 mm (1/8 to 1/4 in.) thick) around the end of the tube, as shown in figure 39. The opening of the injection tube was not restricted. This material was hard and was removed as a “chunk.”

Figure 39. VCD–5A wastewater injection tube and product water pickup tube.

- The compressor gears showed wear, with a gap of 0.330 to 0.419 mm (0.013 to 0.0165 in.) rather than the desired 0.152 mm (0.006 in.), but there were no chips or missing teeth. There was a coating of Vespel® lubricant dust on components of the compressor, as shown in figure 40. Examination under a microscope also showed metallic particles on the Vespel® gear. The recorded time of use for this set of gears is 4,831 hr of cyclic operation. The established life limit for these gears is 12,000 hr of continuous operation. The condition of the gears indicated that they had reached the end of their useful life.

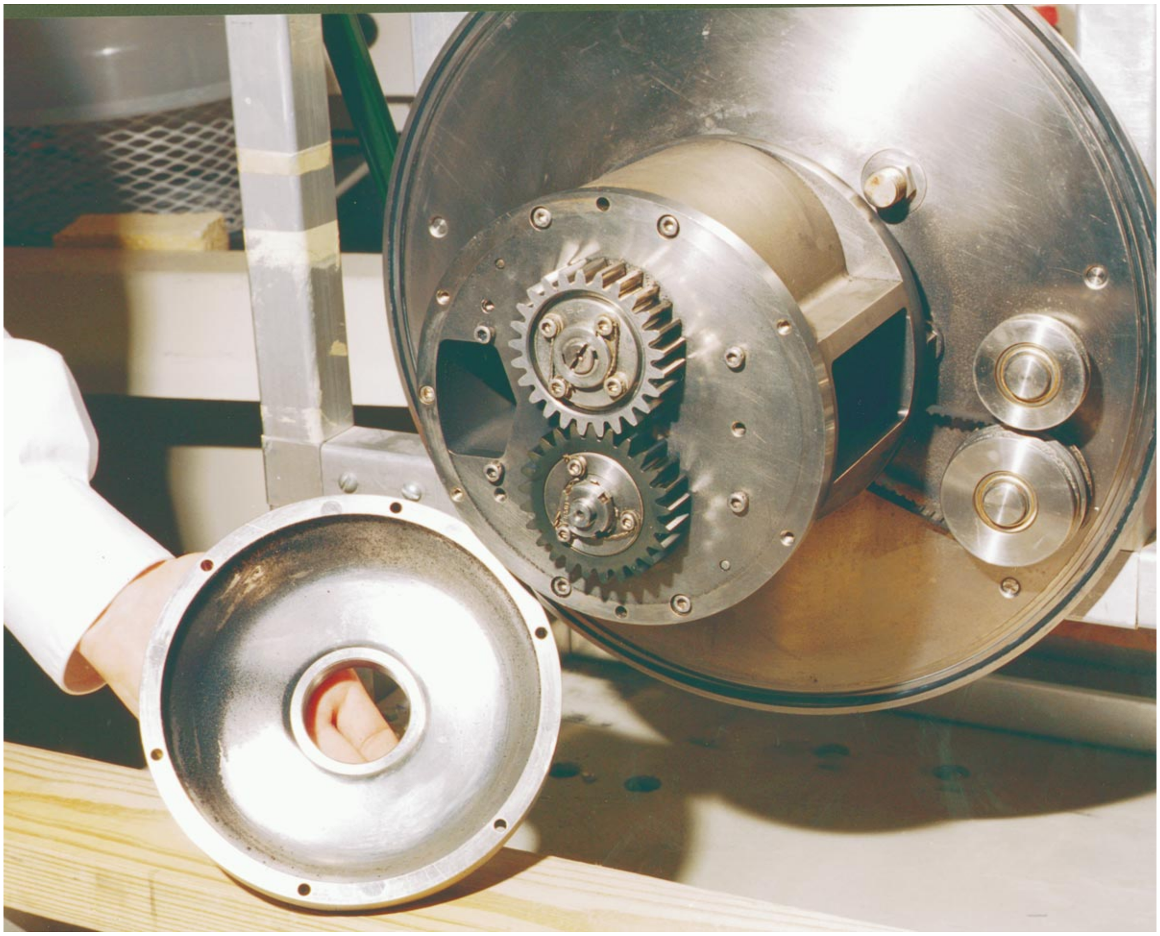

Figure 40. VCD–5A disassembly showing old compressor gears.

- The centrifuge drive belt from the compressor to the drum was stretched about 14 percent. The recorded time of use for this drive belt is 4,831 hr, and the condition indicated it had reached the end of its useful life.

New compressor gears were installed and aligned. The backlash gap measured between 0.102 and 0.152 mm (0.004 and 0.006 in.). The VCD–5A was then reassembled. On January 17, 1996, the VCD–5A was transitioned to *normal* mode. The VCD–5A ran well for 30 min and was returned to *standby* mode. The motor current (I1) was still slightly high at 13A. The VCD–5A was left in *standby* overnight to detect any significant pressure leaks. On January 18, 1996, the measured overnight pressure leakage was only slight (from 37 to 47 mmHg). A second test run was performed for about an hour with no degradation in performance. Again, I1 was slightly elevated at 13A. The VCD–5A was disassembled and a new centrifuge drive belt installed. The compressor gears looked good and the backlash gap remained the same. The VCD–5A was reassembled and restarted. After running for about an hour, I1 jumped from 10A to 18A and the VCD–5A alarmed to *shutdown* mode. No specific cause could be found, but it was thought to be at least partly due to the VCD–5A having been dried out when it was disassembled (dry air doesn't remove as much heat from the compressor as moist air) or too high pressure in the still, which makes the compressor work harder, therefore increasing the current load and operating temperature. The VCD–5A was restarted, and after 3 hr another jump in I1 caused a shutdown. The VCD–5A was again restarted and ran well the rest of the evening (5 hr). The VCD–5A ran well again on January 19, 1996 for 3.5 hr. I1 stayed around 8A.

However, after a period of no operation (such as over a weekend), the unusual behavior was repeated and shutdown occurred about one hour after startup on the following Monday. When the unit was restarted, again, it operated normally and on subsequent days during the week operation was normal. On Monday of test week 159, January 22, 1996, the condenser pressure increased to 54 mmHg and the VCD–5A required additional power to bring the pressure down to normal operating conditions (32 to 45 mmHg). I1 started at 15A and after 15 min dropped to 12.6 A. I1 then jumped to 18A after 45 min in normal and an alarm caused a shutdown. The VCD–5A was immediately restarted and ran nominally with I1 remaining around 8A. The VCD–5A ran nominally for the remainder of the week, as shown in figures 41 and 42.

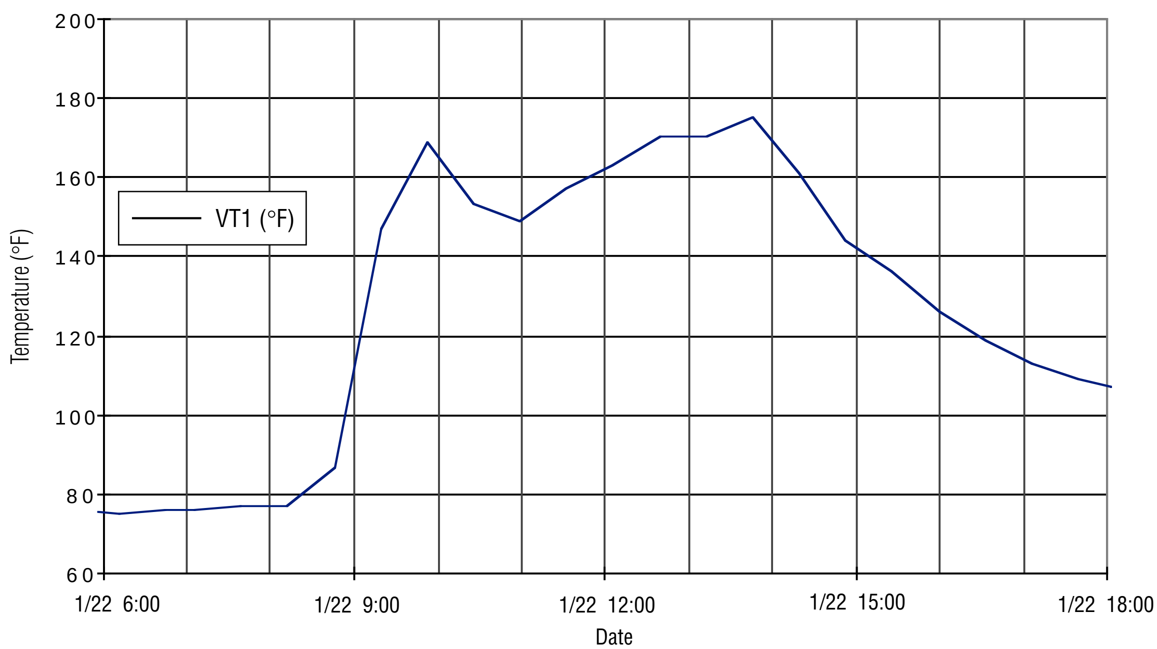

Figure 41. VCD–5A compressor temperature (T1) after repairs in January 1996.

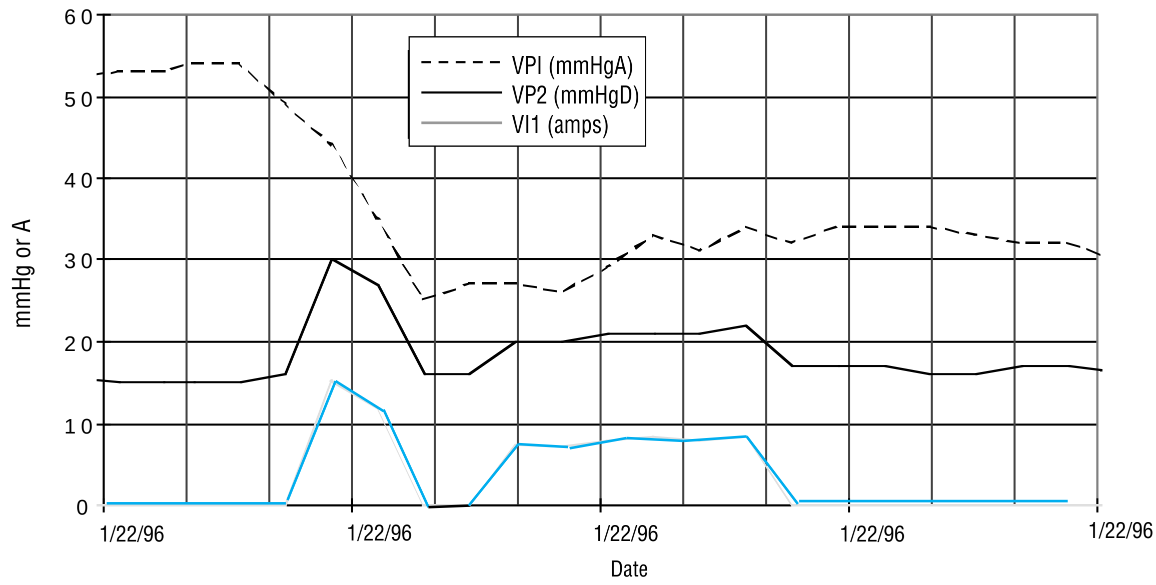

Figure 42. VCD–5A compressor motor current (I1), condenser pressure (P1), and compressor differential pressure (P2) after repairs in January 1996.

On Monday of test weeks 160 and 161, shutdowns were caused by a spike in I1 of the compressor motor. During troubleshooting in February 1996 to determine the cause of the high current draw during startup, the following actions were performed with the indicated results:

- Software changes were made to increase the duration of the initial purge, and facility vacuum was used to “prepurge” the pump casings. These changes helped, but high current draw still occurred during startup after an extended period (a couple of days) of no operation.
- The purge pump unit that was on the VCD–5 was installed on the VCD–5A to determine whether the purge pump was the source of the problem. Operation improved somewhat, but was still not optimal. Another concern, that may be related, is that corrosion was found in the coolant lines when the VCD–5 purge pump was installed on the VCD–5A. This had not caused significant problems but if severe enough, this corrosion could restrict the coolant flow such that insufficient cooling of the purge gases occurs.
- The line connecting the purge pump and fluids pump casings was disconnected and the fluids pump casing was connected to facility vacuum. Measurement of the vacuum showed that leakage was occurring. Application of sealant around the pump motor drive shafts helped, indicating that leakage had been occurring around the drive shafts as well as through other openings in the pump casings. Another source may be leakage through the electrical connectors on the pump casing.

A longer purge was required to compensate for the still leakage over the weekend. Still leakage was not as great during the week because the VCD–5A was in Standby only overnight. The VCD–5A continued to run through test week 168, however, the compressor temperature was higher than nominal.

4.5.3 VCD–5A Operation Summary

From mid-1993 to late-1995 performance was essentially nominal. The problems that did occur were easily corrected.

From November 9, 1995 to the end of testing, startup and operation were increasingly assisted by facility vacuum due to increasing leakage. The compressor gears installed in January 1996 initially solved the high compressor temperature (T1) problem. However, as the VCD–5A life test continued, problems developed with high motor current draw (I1) and high compressor temperatures (T1). Leakage in the VCD–5A was greater than could be compensated for by using the facility vacuum. Except for startup on Mondays, when the VCD–5A had not operated for 2 days, the VCD–5A could have run without the facility vacuum, but purge periods would have been longer, so the facility vacuum was used whenever the VCD–5A was running. That the weekend downtime created a problem indicates a leak into the still or pump housings which raised the internal pressure too high for the purge pump to overcome. Life testing of the VCD–5A was halted after completion of the Purge Gas Test on April 24, 1996.

4.5.4 Proposed Modifications

To address the problems experienced with the VCD–5A, the following modifications have been funded in FY98:

- Modify the pump drive shaft seals to make them flight-like (fluids pump and purge pump).
- Replace the tubing in the purge pump.
- Replace the demister with a flight design (not related to the problems described above).
- Replace the recycle/filter tank with a flight design (not related to the problems described above).

In addition, the purge algorithm or setpoints may need to be modified and this modification implemented in the *ISS* VCD/UPA.

5. TEST RESULTS AND LESSONS LEARNED

The results of the life testing of the VCD–5 and VCD–5A have led to numerous improvements in the flight design. For example, lessons learned about the VCD relate to the critical nature of pump drive mechanism alignment and the impacts of quality control on system performance. Although the problems have been resolved, the number of problems relating to quality control and the sensitivity of hardware performance are causes for concern. General results and lessons learned, and specific results and lessons learned about each component for the VCD–5 and VCD–5A are discussed in the following sections.

5.1 General Results and Lessons Learned

The operating lifetimes of VCD components are listed in table 15. The lifetimes of most of the components are greater than the duration of the life test. The times indicate time of operation of that component, excluding *standby* and *shutdown* conditions, except where "operation" is continuous such as the WSA and FCA. The overall production rates and the performance of each component are discussed below.

Table 15. VCD component lifetimes.

Component	Lifetime
Wastewater storage assembly	> 21,000 hr (test duration) (not replaced)
Fluids control assembly	> 21,000 hr (test duration) (not replaced)
- Waste recycle pressure sensor (P3)	> 21,000 hr in the wastewater environment
Fluids pump assembly	
- Harmonic Drive	> 2,676 hr of operation when properly aligned, otherwise <400 hr
- Norprene® tubing	> 3,076 hr in use (not replaced)
Distillation assembly	
- Compressor motor	> 3,107 hr of operation (not replaced)
- Compressor gears	4,800 hr of operation (includes time before the Life Test began)
- O-ring drive belt	4,800 hr of operation (includes time before the Life Test began)
- Condenser pressure sensor (P2)	>1,600 hr
Recycle filter tank	
- Filter (dual 25 μm pore size spiral wound) - Filter (single 10 μm pore size, pleated)	average 20.6 days of operation insufficient run time to determine
Pressure control assembly	> 21,000 hr (test duration) (not replaced)
Purge pump assembly	
- Harmonic Drive	> 1,285 hr of operation when properly aligned, otherwise <400 hr
- Norprene® tubing	> 1,285 hr of operation (but spalling indicates a limited life when used in the purge pump) (not replaced)
- Gas/liquid separator	unknown, due to contamination by Norprene® particles
- Pressure regulator	unknown, due to contamination by Norprene® particles
Sensors	no flight-like sensor failed
Valves	no flight-like valve failed

5.1.1 Variation of Production Rate

The calculated average production rates of the VCD/UPA's that have been tested at MSFC have shown significant variation, ranging from 1.48 to 2.04 kg/hr (3.25 to 4.50 lb/hr). The reasons for this variation relate to:

- Hardware variability due to differences in pump performance, quality control, etc.
- Operational variability due to shutdowns, component failures, facility variability, etc.
- Methods for calculating the production rate.

Regarding the calculation methods, during the course of testing VCD/UPA's at MSFC, the data has been recorded in different manners for different tests. The single largest variable has been the transition time from *standby* to *normal* and from *normal* to *standby*. For some testing, transition times were not separately recorded, resulting in apparently reduced production rates. The duration of the transition times also has varied considerably due to hardware condition and operation procedures. Thoroughly evacuating the purge pump and fluids pump casings reduces the transition durations, thereby increasing the effective processing rate when transition periods are used in calculating the processing rate.

Another factor is calculating the production rate using the product water versus using the input wastewater. When input wastewater is used for the calculation the processing rate is higher, obviously, than when the product distillate is used.

The effects of using different methods to calculate the processing rate are shown in table 16. While it is likely that the production rate of the VCD–5 was greater than the production rate of the VCD–5A, due to the variability in transition durations the calculated production rates shown in the table cannot be directly compared. This was not realized for all testing and the *normal* operating duration was not always recorded. To ensure accurate comparison of different test runs, the same procedures for calculating the production rate must be used. It is recommended that input wastewater mass, product distillate mass, and the time in *normal* be recorded and used in the calculations for future testing and operation.

Table 16. Average processing rate calculations.

	VCD–5 During WRT Stage 10	**VCD–5A Jan. 12, 1993—Nov. 9, 1996**
Input Wastewater Mass	1,262.4 kg (2,777.3 lb)	5,198 kg (11,449 lb)
Product Distillate Mass	1,092.0 kg (2,402.5 lb)	NA
Duration of Operation		
Including Transition	565 hr	3,807 hr
Normal Only	NA	2,960 hr
Production Rate		
Wastewater ÷ Normal	NA	1.76 kg/hr (3.87 lb/hr)
Wastewater ÷ (Normal + Transition)	2.23 kg/hr (4.91 lb/hr)	1.37 kg/hr (3.01 lb/hr)
Distillate ÷ Normal	NA	NA
Distillate ÷ (Normal + Transition)	1.93 kg/hr (4.25 lb/hr)	NA

NA = not available

5.1.2 Wastewater Supply

The check valve between the external wastewater supply tank and the WSA failed early in the test period for both the VCD–5 and VCD–5A. This valve corresponds to the flight valve between the urinal and the WSA. The cause of the failure was due to insufficient spring constant to keep the spring from being deformed while being in one position for extended periods. While this spring is not flight-like, it points out an aspect which should be evaluated in the flight valve.

5.1.3 Instrumentation and Valve Failures

During troubleshooting it was found that a capacitor had failed and caused a power converter to also fail on one of the circuit cards. Both faulty parts were replaced and the repaired circuit card returned to the signal conditioner.

Valve V3, between the pump housing and the distillation unit, was not opening properly due to incorrect wait timer commands from the EPROM (which had been inadvertently set incorrectly) and the VCD–5A was shutdown. The wait timer was reset to the correct duration.

5.1.4 High Conductivity of Product Water

At startup high conductivity of the product water usually occurs after the still has been pressurized above the normal operating pressure. This anomaly has not been resolved. Particles from the compressor Vespel® gear were found in the product water of all VCD/UPA's which may contribute to high conductivity readings.

5.1.5 Materials

Particles of Norprene® tubing from the purge pump have been found in at least three VCD units (the VCD–5, VCD–5A, and a development VCD/UPA). The life of the purge pump may not be affected, but Norprene® particles have clogged the gas/water separator and the pressure regulator, and have been found in the product water.

Norprene® tubing is intended for use in mostly liquid pumping, while in the VCD/UPA purge pump there is mostly gas in the fluid stream being pumped, which increases mechanical wear and degradation (spalling). In addition, the manufacturing process can leave particles of tubing material loosely attached to the internal wall of the tube and flow through the tube will detach the particles.

The problems experienced with the Norprene® tubing in the purge pump have resulted in the possible addition of a filter to the flight design. The life of this filter is being specified to be consistent with the purge pump assembly to minimize routine maintenance requirements. Although the problems have been resolved, the number of problems relating to quality control and the sensitivity of hardware performance is cause for concern. Degradation of the fluids pump and purge pump Norprene® tubing must be eliminated or controlled in order to avoid premature failure of the gas/water separator, the pressure regulator, valves, and sensors. If a more durable tubing material is not feasible then a filter downstream of the fluids pump is needed. Cleaning the tubing with high pressure water or gas prior to installation will remove existing particles.

5.1.6 Leakage

When new, the purge pump tubing may have been capable of removing air that leaked in but over time degraded to the point where it cannot perform adequately even with the assistance of the facility vacuum. Because of this possibility, it is not known whether the leakage has increased or the capability of the purge pump to deal with leakage has declined, or both. Samples collected from the VCD–5 purge pump contained bits of material that appear to be the tubing material, indicating spalling of the material which could lead to degradation in performance. In addition, corrosion in the VCD–5 fluids pump led to leakage through the housing which was very likely in the a significant factor. The flight VCD will have pump housings made of titanium.

5.1.7 Harmonic Drive Failure

Lessons learned about the VCD also relate to the critical nature of pump drive mechanism alignment. During previous testing using the Harmonic Drive, this failure did not occur. One design change that may have affected this was the use of an additional bearing support for the motor instead of the previous single-point cantilever attachment, which apparently was more tolerant of misalignment. Although the test hardware misalignment may have resulted from a pump retrofit, the flight design has a similar drive mechanism alignment requirement. The investigation of failures experienced in the fluids pump has concluded that fatigue caused by a horizontal misalignment was the major contributor and that when such a misalignment occurs, the drive life will not exceed 400 hr. The hardware supplier has implemented use of a new alignment jig during hardware assembly to provide proper alignment. This jig will be used for flight hardware assembly. Although the problem appears to have been solved, the sensitivity of the VCD to such problems indicates a lack of design robustness and a need for close attention by quality control personnel to prevent such problems during flight unit assembly.

5.2 VCD–5 Test Results

The test results are described below for each component.

5.2.1 Wastewater Supply Tank

No hardware problems were related to the wastewater supply tank. When operating on Earth, any free gas in the supply wastewater collects at the top of the tank where the outlet line is located, leading to high compressor temperature alarms when the gas is injected into the distillation unit.

5.2.2 Fluids Pump

On test day 17 the fluids pump housing and drive shaft seal were found to be leaking, at a rate of 15 to 20 mmHg/hr. This leakage reduces the effectiveness of the purge pump for maintaining a suitable vacuum, therefore reducing the processing rate.

5.2.3 Purge Pump

Vacuum leakage into the VCD–5 still was higher than expected. When the pressure in the still cannot be maintained low enough, performance is decreased and a shutdown may occur. The most likely source was the purge pump drive shaft seal and a purge valve, which seemed to have failed, as well as leakage through the back pressure regulator and fluids pump. These leaks, in combination, caused the purge pump to lag behind in evacuating the still and not be able to keep the pressure sufficiently low. The resolution was to replace the faulty valve, tighten the pump housing, and change the control software for the purge algorithm, so the pump stayed on longer during the purge. This change to the software also made it more tolerant of leakage so that a small leak will not cause a dramatic change in pressure. This was successfully tested using a facility pump to assist the purge pump.

The purge algorithm provides a 1 min purge of the pump casing, then a 2 min purge of the still. If P1 reaches 27 mmHg before 2 min then it repeats another 2 min purge. Double or triple purges indicate leakage of ambient air (noncondensable gases). An initial increase in pressure indicates leakage in the purge pump.

During investigation of the difficulty for the purge pump to maintain a suitable vacuum it was found that the Norprene® tubing in the purge pump was spalling. Small pieces of Norprene® material were found in the back pressure regulator, which prevented proper sealing, and in the gas/water separator. This resulted in leakage into the still and blockage of purge gas flow, respectively, and reduced performance. The pressure regulator was cleaned and reinstalled.

5.2.4 Distillation Assembly

During troubleshooting, the VCD–5 was disassembled and the still drive belt was found to have been incorrectly installed. This had resulted in numerous low speed alarms. The belt was reinstalled correctly and the problems did not recur. It was also found that an O-ring seal had not been installed. Use of a fan to cool the compressor motor, increasing the duration of the purge, installation of a sample port that also vented free gas from the WSA, and replacement of the Vespel® gear all helped to reduce the compressor temperature and eliminate shutdowns and warnings.

5.2.5 Recycle Filter Tank

No problems were found with the operation of the recycle filter tank. Filter replacement and tank cleaning was performed as expected.

5.2.6 Gas/Water Separator

During repairs on January 13, 1994 the gas/water separator was removed and particles of Norprene® tubing material were found inside, blocking the separator inlet and fouling the filter medium. The separator was cleaned and back flushed before being reinstalled. When Norprene® particles were found again later, the gas/water separator was replaced.

5.3 VCD–5A Test Results

The test results are described below for each component.

5.3.1 Wastewater Supply Tank

No hardware problems were related to the wastewater supply tank. As with the VCD–5, the presence of free gas in the wastewater supply tank may have contributed to high compressor temperature alarms.

5.3.2 Fluids Pump

The fluids pump failed during pretest checkout after about 400 hr of operation due to a sheared flex spline in the Harmonic drive. This drive was replaced prior to beginning the life test, but after 360 hr of operation the same failure occurred again. The cause was a slight horizontal misalignment. The hardware supplier made an alignment jig to ensure accurate installation and the problem did not recur.

Leakage around the pump drive shaft seals was also found to be significant (as for the VCD–5). The flight VCD/UPA will have redesigned seals.

5.3.3 Purge Pump

Norprene® tubing particles were shed from the purge pump, as with the VCD–5.

5.3.4 Distillation Assembly

High compressor temperature and low centrifuge speed alarms occurred occasionally beginning 367 and 434 days, respectively, into the life test.

The high temperatures were likely due to excess friction in the compressor gears as they approached the limit of their recommended lives. Through November 9, 1995, the operating time on the compressor gears and the drive belt was about 4,831 hr including time before the Life Test began. These components were near the end of their design life. Another contributing factor may be free gas in the wastewater feed.

At startup, high conductivity of the product water usually occurs after the still has been pressurized above the operating pressure. This anomaly has not been resolved. Particles from the compressor Vespel® gear were found in the product water of all VCD/UPA's which may contribute to high conductivity readings.

The metal demister was found to shed tiny slivers of stainless steel (like steel wool) which were found in the phase separator with the Norprene® tubing particles. This has only occurred on one VCD but may be a generic problem. The slivers were similar to metal taken (easily removed) directly from the demister inside the distillation unit.

When the VCD–5A was disassembled during troubleshooting it was also found that an O-ring seal had not been installed between the stationary bowl and the separator plate (as with the VCD–5).

5.3.5. Recycle Filter Tank

The waste recycle pressure sensor (P3) failed on August 9, 1993 and a temporary sensor was installed on August 30, 1993. The temporary sensor failed on February 1, 1994 and was removed. The materials in these sensors could not tolerate the wastewater environment. Both are flight-like in function, but not material. A new, flight-like sensor made of Inconel 718 was installed on July 19, 1994.

A leak was found in the waste recycle relief valve, caused by corrosion of the pipe connector fittings. The fittings were replaced with identical fittings, flight-like in function only. A vacuum leak test was performed on the fluids pump assembly and the purge pump housing, and no leaks were found.

The filters lasted an average of 20.62 days each.

5.3.6 Gas/Water Separator

As with the VCD–5, particles of Norprene® tubing material were found in the gas/water separator, causing as much as 60 percent blockage.

6. CONCLUSIONS AND RECOMMENDATIONS

The VCD life test program has successfully met the objectives as stated in section 1. Recommendations concerning the *ISS* VCD/UPA can be grouped into four categories: design, quality control, materials, and operation.

6.1 Design

Redesign of the purge pump and fluids pump drive shaft seals is recommended to prevent leakage into the pump housings. The drive shaft seals have been redesigned for the *ISS* VCD/UPA. Other potential leak sites, such as connectors, should be designed to preclude leakage, and verified to ensure no significant leakage.

Due to the potential for metal slivers to be shed from the stainless steel demister, an alternative design is recommended. The demister has been redesigned to be a membrane-type for the *ISS* VCD/UPA.

Wearing of the Vespel® gear in the compressor is expected because the Vespel® gear adds lubrication as it wears. However, traces of Vespel® were found in the product water, in all operating VCD/UPA's. A filter in the product water line is recommended to ensure that the allowable particulate level of the product water will not be exceeded.

The wastewater feed tank design, with the outlet at the top, allows free gas to collect and contribute to overheating and other problems during ground testing. This effect would not likely occur in orbit since any free gas will be distributed in the liquid, but must be considered during ground testing. Unless this free gas is removed prior to beginning a processing cycle, high compressor temperatures and high current draws will result when the gas is injected into the distillation unit.

6.2 Quality Control

The Harmonic Drives of the purge and fluids pumps must be properly installed with careful attention to the drive mechanism alignment.

Care must be taken during assembly to ensure proper installation of components such as the centrifuge drive belt and O-rings.

6.3 Materials

To prevent premature failure of sensors and valves, it is essential that materials be compatible with the environments where the sensors or valves are located, especially the harsher environments such as the wastewater recycle lines. It is recommended that long-term material compatibility be verified for all components.

To prevent particles of Norprene® tubing from the purge pump from clogging components, it is recommended that the tubing be cleaned with high pressure water or gas prior to installation to remove any particles present due to the manufacturing process, and that a filter be added downstream of the purge pump to ensure that any new particles generated do not cause problems.

To prevent corrosion of the fluids pump and purge pump in the event of leakage, the housings will be made of titanium for the flight VCD.

6.4 Operation

It is very important to thoroughly evacuate the fluids pump and purge pump housings prior to evacuating the still, and to have a sufficient purge duration prior to transitioning to *normal* operation from *standby.* It is recommended that the purge duration be increased for this reason. This control change to increase the duration of purge will be implemented on the *ISS* VCD/UPA and all currently operating VCD/UPA's.

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APPROVAL

FINAL REPORT ON LIFE TESTING OF THE VAPOR COMPRESSION DISTILLATION/ URINE PROCESSING ASSEMBLY (VCD/UPA) AT THE MARSHALL SPACE FLIGHT CENTER (1993 TO 1997)

P. Wieland, C. Hutchens, D. Long, and B. Salyer

The information in this report has been reviewed for technical content. Review of any information concerning Department of Defense or nuclear energy activities or programs has been made by the MSFC Security Classification Officer. This report, in its entirety, has been determined to be unclassified.

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13. ABSTRACT *(Maximum 200 words)*

Wastewater and urine generated on the *International Space Station* will be processed to recover pure water using vapor compression distillation (VCD). To verify the long-term reliability and performance of theVCD Urine Processor Assembly (UPA), life testing was performed at the Marshall Space Flight Center (MSFC) from January 1993 to April 1996. Two UPA's, the VCD-5 and VCD-5A, were tested for 204 days and 665 days, respectively. The compressor gears and the distillation centrifuge drive belt were found to have operating lives of approximately 4,800 hours, equivalent to 3.9 years of operation on *ISS* for a crew of three at an average processing rate of 1.76 kg/h (3.87 lb/h). Precise alignment of the flex-splines of the fluids and purge pump motor drives is essential to avoid premature failure after about 400 hours of operation. Results indicate that, with some design and procedural modifications and suitable quality control, the required performance and operational life can be met with the VCD/UPA.

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