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PRELIMINARY FLIGHT PROTOTYPE POTABLE WATER BACTERICIDE SYSTEM

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PRELIMINARY FLIGHT PROTOTYPE POTABLE WATER BACTERICIDE SYSTEM

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October 1973

A Subsidiary of AMGLO Industries

This report summarizes the results of the work performed by CHEMTRIC Incorporated under Contract NAS 9-12792 for a Preliminary Flight Prototype Potable Water Bactericide System. This program was sponsored by and performed for the Crew Systems Division of the NASA Johnson Spacecraft Center. Mr. A.F. Behrend (EC39) was the designated Technical Monitor.

The work reported herein was started in March 1972 and completed in June 1973. Chief program personnel were Walter J. Jasionowski (Project Engineer) and Edward T.Allen (Project Chemist) under the direction of Robert A. Bambenek (Program Manager). Other personnel that made substantial contributions to this program are: Phillip P. Nuccio (Design Supervisor), Timothy G. Studt (Design Engineer) and Andrew L. Murman (Technician). Mr. Charles Verostko of the NASA Johnson Spacecraft Center provided assistance by co-ordinating and supervising the analysis of over 1000 individual water samples.

The development, design, and testing of a Preliminary Flight Prototype Potable Water Bactericide System are described. Preliminary development tests were performed to resolve problems experienced under Contract NAS 9-12104 which affected water quality and silver ion dosing. After satisfactory completion of the preliminary development work, two simulated mission tests, each of 7 days duration, were performed with an upgraded breadboard system to demonstrate improved performance and to show that biochemical performance is not affected by random vibrations which simulate launch conditions.

A Preliminary Flight Prototype system was designed and fabricated to treat worst case FCW simulant. The system is an assembly of upgraded canisters composed of (1) a biological filter, (2) an activated charcoal and ion exchange resin canister, (3) a silver chloride canister, (4) a deionizer, (5) a silver bromide canister with a partial bypass, and (6) mock-up instrumentation and circuitry. A 7-day baseline simulated mission test was performed with the system; the performance was satisfactory and the product water was within all specifications for potability. After random vibrations, an 18-day simulated mission test was also performed which included bacteria injection during the first 10 days; the product water quality was within potability specifications for the first 13 days. The system exhibited bactericidal activity against 10^9 Pseudomonas aeruginosa and/or Type IIIa, and reduced Bacillus subtilis by up to 5 orders of magnitude in 24 hours at ambient temperatures with a 1 ppm silver ion dose.

Five extended simulated mission tests were performed with modified PFP systems to determine the effects of FCW constituents and their concentration on the number of components required to produce acceptable water. A Pratt & Whitney FCW treating system composed of (1) an in-depth 1-micron particulate filter, (2) a AgCl column and (3) a deionizer with a partial bypass, exhibited 27.5 to 32.9% dynamic absorption capacity before pH breakthrough. A General Electric FCW treating system, composed of (1) a biological filter, (2) an ion exchange column, (3) a AgCl column, and (4) a deionizer with a partial bypass exhibited 21.6 to 25.2% dynamic absorption capacity before pH breakthrough. From the tests it is concluded that (a) the bactericidal/bacteriostatic efficacy of these systems is the same as the PFP, (b) in-depth filters do not effectively exclude bacteria and particulates and (c) the ion exchange resins did not sorb the organics (equal part mixture of toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone and xylenol) adequately to meet potability specifications for odor and taste.

Four efficacy tests were performed with a AgBr canister dosing anticipated fuel cell water. Tests show that a 0.05 ppm silver ion dose was bactericidial against $3 \pm 1 \times 10^9$ ($5 \pm 1 \times 10^4$/ml Pseudomonas aeruginosa and/or Type IIIa in 15 minutes or less.

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INTRODUCTION & SUMMARY

1.1 Background

The Space Shuttle Orbiter is to use hydrogen-oxygen fuel cells to generate electric power, and water for consumption and personal hygiene. In general, fuel cell water is relatively pure because it is synthesized from hydrogen and oxygen and has undergone a phase change from an alkaline electrolyte. However, the experience gained from Project Gemini and Project Apollo indicates that fuel cell water can contain (1) trace contaminants which affect it's taste, odor, and potability and, (2) microbial contaminants. In addition, even presterilized water stored onboard a spacecraft is easily contaminated via the crew use points unless the water contains a residual bactericide or is stored at an elevated temperature. Consequently, the Space Shuttle Orbiter should be provided with a water treatment system which assures the availability of fuel cell water which is sterile, potable and acceptable to the crew.

The Gemini fuel cell water was not consumed by the crew because it had a low pH, poor taste and poor color. Furthermore, limitations prevented the development of a suitable treatment system. Instead, the crew consumed potable water stored in bladder-type tanks which were also used to accumulate the fuel cell water.

Corrosion, poor taste and free gas problems have been encountered with the Apollo fuel cell water.* The chlorine, which is added to assure sterility, accelerates corrosion. In addition, chlorine must be added once every day during the mission because the chlorine reacts with trace contaminants and the construction materials. A "chlorine" taste has been noted whenever the crew failed to follow precise dosing procedures; in addition, a "nickel" taste, which is attributed to accelerated corrosion of stainless steel in the water heater, has been present.

The Apollo Lunar Module crews have all consumed stored water dosed with iodine. Initially, sodium hypochlorite was tried, but abandoned when it was found that chlorine hydrate accumulated on the sublimators which also use the stored water.** It was also discovered that iodine diffuses through the sili-

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* Samonski, F. H. and Tucker, E. M., "Apollo Experience Report - Command and Service Module Environmental Control System", NASA TN D-6718, March 1972.

** Gillen, R. J., Brady, J.C. and Collier, F., "Apollo Experience Report - Lunar Module Environmental Control Subsystem" NASA TN D-6724, March 1972

cone-rubber bladders in the tanks and reacts with the anodized aluminum tank wall. Fortunately, the iodine depletion and corrosion rates are slow, so that in-flight maintenance and failures can be avoided by not exposing the tanks to iodine until just before the vehicle is launched.

All of the water management problems encountered by Project Gemini and Project Apollo indicate that a more durable system should be provided for future spacecraft - and especially for the reusable Space Shuttle. Also, a residual bactericide, which can be passively added to the fuel cell water as the water is produced, should be used instead of chlorine or iodine. In addition, the water quality should be improved to avoid any noxious tastes and/or odors which can be introduced by the fuel cell materials - expecially when the fuel cells are operated at any off-design conditions.

CHEMTRIC had evaluated the use of silver ions for sterilizing water distilled from urine, treated flush water and concentrated wash water.*,** In all cases, condensate passed through a column containing silver chloride particles was found to be sterile for months - even though the condensate contained some organic contaminants and was exposed to the laboratory atmosphere. In addition, no corrosion problems were observed in stainless steel hardware which had been exposed to silver-saturated water for up to four years. Thus, silver ions were selected as the residual bactericide to be evaluated for use in the Space Shuttle Water Treatment System.

Under Contract NAS 9-12104 CHEMTRIC designed and fabricated a breadboard model to evaluate the use of silver ions in the Space Shuttle; Figures 1 and 2 illustrate the system. As shown in these figures, the system includes (1) a biological filter for removing particulates, (2) an activated carbon filter for adsorbing organic contaminants, (3) a canister of silver chloride particles for dosing the water to be stored with silver ions (1ppm), (4) water storage and material immersion tanks, (5) a deionizer for removing silver ions and inorganic contaminants, and (6) a canister of silver bromide particles for dosing the product water with a smaller quantity of silver ions (0.05 ppm).

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* Nuccio. P.P., et al., "Refurbishment and Testing of the Integrated Waste Management System", AMGLO Report 3080, Chicago, Illinois, October 1969.

** Bambenek, R.A., et al., "Upgrading and Extended Testing of the MSC Integrated Water and Waste Hardware", CHEMTRIC Report 3084, Rosemont, Illinois, May 1972.

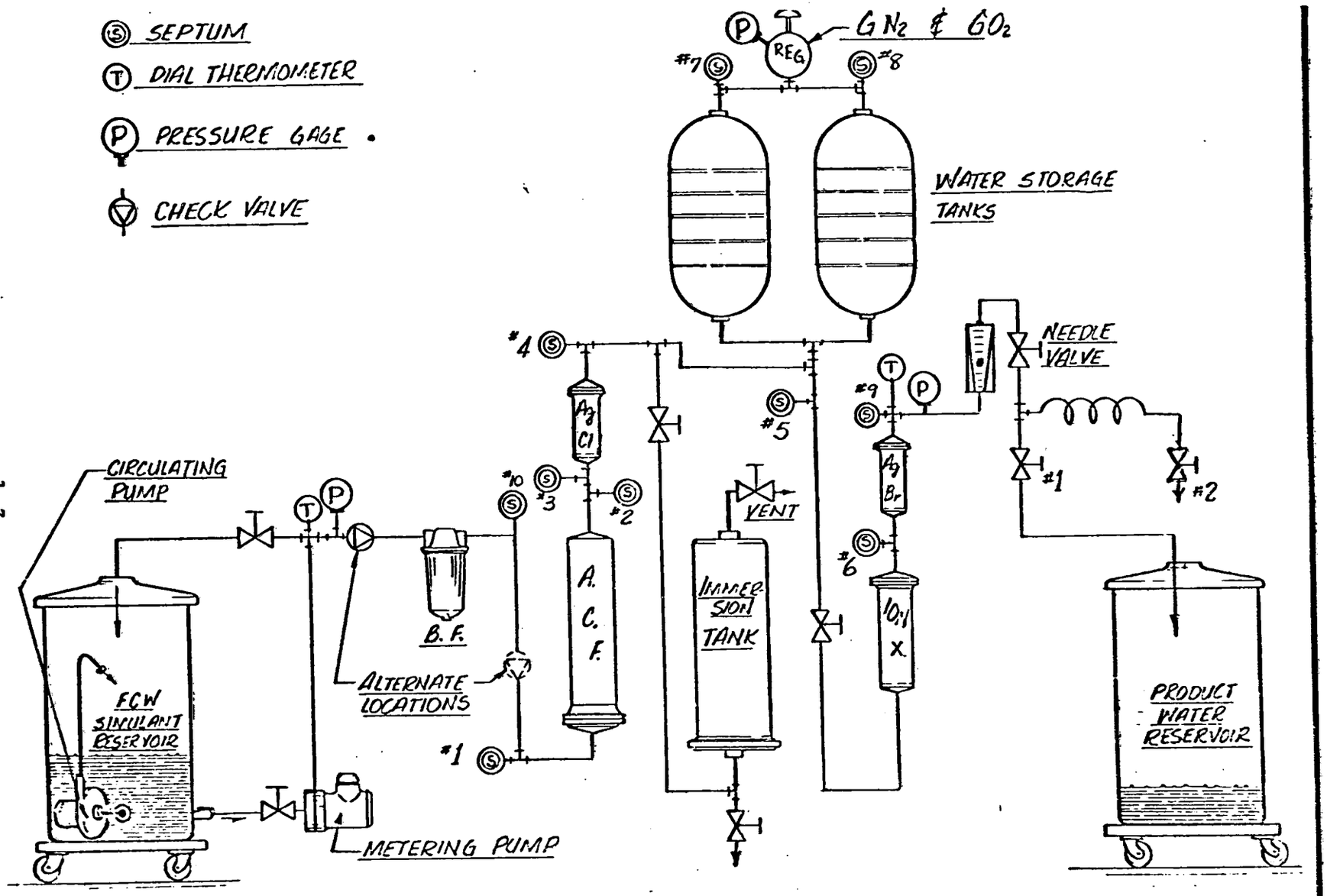

Figure 1 SCHEMATIC OF BREADBOARD SYSTEM

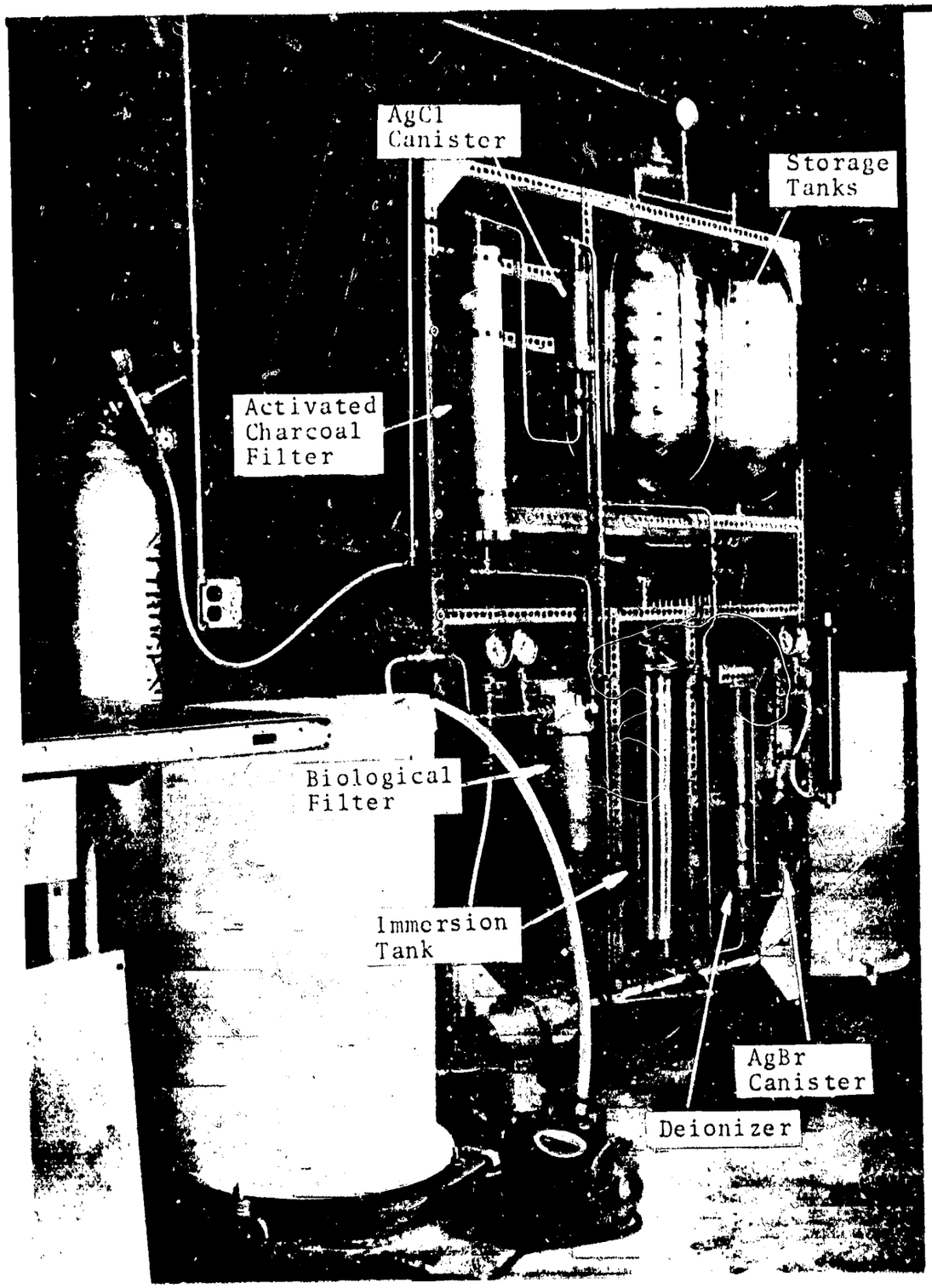

Figure 2 PHOTOGRAPH OF BREADBOARD SYSTEM

Support equipment included (1) holding tanks for simulated fuel cell water and product water, (2) a feed pump, and (3) miscellaneous items such as valves, gages and septums.

Five simulated mission tests were performed with this hardware to demonstrate that silver ions are capable of (1) killing 3 x 109 Pseudomonas aeruginosa and/or Type IIIa bacteria in periods as short as fifteen minutes and (2) reducing the concentration of Bacillus subtilis, a spore-forming bacteria, by five orders of magnitude (10^4 to 10^{-1}) in 24 hours. This work showed that silver ions are extremely effective in maintaining potable water in a sterile condition.

Technical problems, which affected water quality and silver ion dosing, were experienced with the breadboard system developed under Contract NAS 9-12104. The deionizer was not able to produce water with the desired pH, and the activated charcoal filter was unable to adsorb the organic specie (ethylene glycol) from the simulated fuel cell water. Also, the presence of chloride ions in the simulated fuel cell water, suppressed the solubility of AgCl by at least one order of magnitude.* Furthermore, the AgBr column did not produce the desired silver ion concentration (0.05 ppm maximum for potability). With this knowledge and information NASA JSC contracted CHEMTRIC to perform the work summarized by this report.

1.2 Objectives

The detail objectives of this program are delineated by the Task Description defined in Section 3.2 of the Statement of Work for Contract NAS 9-12792; they are described as follows.

Par 3.2.1 Deionizer Optimization and Activated Charcoal Improvement

The product water produced by the breadboard system developed under Contract NAS 9-12104 did not possess neither the specified pH (6.0 - 8.0 at 77°F) nor the silver ion concentrations (0.05 ppm maximum) required for potability.

(a) Determine the type, quantity and arrangement of ion-exchange resin required in the deionizer to obtain an effluent which has the specified pH and silver ion concentration.

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* Hurley, T. L., and Bambenek, R. A. "Potable Water Bactericide Agent Development", NASA CR-115595, July 1972.

(b) Using the deionizer and presterilization procedure developed under Contract NAS 9-12104, perform a series of tests with known silver-dosed "worst case" simulated fuel cell water and various ion exchange resin combinations to optimize the deionizer.

(c) Test the deionizer with the optimum resin combination repeatedly to verify performance with respect to pH and silver ion concentration.

(d) Investigate inclusion of ion exchange resins in the activated charcoal filter to remove any chlorides to minimize the "common ion" effect.

Par 3.2.2 Breadboard Canister Shock/Vibration Testing

Subject the breadboard system canisters to shock and vibration tests which simulate the Space Shuttle launch environment to verify canister biochemical and hydraulic performances. These canisters (i.e., the activated charcoal, silver chloride, silver bromide and ion exchange beds) are to be "freshly loaded" and subjected to the following simulated Shuttle launch conditions.

(a) Launch "G" Load (G in any direction): 3

(b) Liftoff/Boost Random Vibration Levels: 2.5 minutes in each of 3 mutually perpendicular planes.

20 to 80 cps	3 dB/oct increase
80 to 180 cps	0.06 g^2/cps
180 to 200 cps	12 dB/oct increase
200 to 400 cps	0.1 g^2/cps
400 to 450 cps	-12 dB/oct decrease
450 to 2000 cps	0.06 g^2/cps

Fabricate a test fixture(s) to permit simultaneous exposure of all canisters to the shock and vibration environments.

Par 3.2.3 Breadboard System Performance Testing

(a) Perform a baseline test before subjecting the canisters to the simulated launch environments.

(b) After shock and vibration testing, subject the breadboard system canisters to a 7-day simulated mission test using "worst case" simulated fuel cell water and evaluate their biochemical and hydraulic performances.

Par 3.2.4 Preliminary Flight Prototype Design

Prepare a design of a preliminary flight prototype water bactericide system, after completing the breadboard system performance tests. The design is to be based upon (1) the results of Contract NAS 9-12104, (2) the results of the breadboard system performance tests, and (3) the results of the shock and vibration tests. The design is to interface with the Space Shuttle, emphasize simplicity, and incorporate the flight characteristics of low weight, low pressure drop, maintainability, and compactness.

Par 3.2.5 Preliminary Flight Prototype Fabrication

Fabricate a preliminary flight prototype of the potable water bactericide system. All materials used in the construction are to be compatible with the working fluid (simulated fuel cell water) and the Space Shuttle environment.

Par 3.2.6 Simulated Shuttle Mission Testing

Test the preliminary flight prototype system to verify performance and design requirements.

(a) Perform a baseline test.

(b) Subject the system to the simulated Shuttle launch environment specified in paragraph 3.2.2.

(c) Perform mission testing after shock and vibration tests with "worst case" simulated fuel cell water and biological contaminants.

The two candidate fuel cells (Pratt & Whitney and General Electric) produce a fuel cell water which differs from "worst case" fuel cell water simulant. Following the completion of "worst case" fuel cell water tests, Extended Tests were performed with modified Preliminary Flight Prototype systems composed of a minimum number of components, treating various grades of Pratt & Whitney and General Electric fuel cell water simulant. The objectives of these tests were to simplify the system (i.e., reduce the number of components) and to determine their useful life. With Amendment/Modification No. 1S, Paragraph 3.2.6 was amended by adding the following:

"Following completion of these 'worst case fuel cell water' system tests the preliminary flight prototype system components shall be tested with various grades of simulated fuel cell water to define the minimum bactericide system

requirements for processing 'cleaner' fuel cell water. the useful life and dynamic performance of each component shall be determined. A minimum of six simulated mission tests shall be performed using three different compositions of simulated fuel cell water (with and without chlorides), and bacteria shall be injected daily. Sufficient water sampling and analyses shall be performed to verify product water potability and to determine when system useful life is exceeded".

1.3 Accomplishments

The work performed under Contract NAS 9-12792 yielded the following results and conclusions which are described in further detail on the pages listed in parentheses.

1.3.1 Preliminary Tests

A. Experiments conducted with ion exchange resin mixtures show that a mixed resin bed composed of 200 ml Amberlite IR-120, 150 ml Amberlite IRA-402 and 100 ml Amberlite IR-45, produces an effluent which has the specified pH (6.0 - 8.0). It is concluded that the addition of the strong base anion exchange resin Amberlite IRA-402 prevented breakthrough of acids (primarily HF) which are not satisfactorily absorbed by the weak base anion exchange resin Amberlite IR-45 (pp 2-1 to 2-4).

B. Tests with ion exchange resins included in the activated charcoal canister showed that the silver ion concentration in the stored water increased to greater than 1 ppm from 0.08 - 0.10 ppm. Removal of chlorides reduce the "common-ion" effect on the solubility of AgCl (p 2-4).

C. Extraction tests on various nonmetallics used in the construction of fuel cells indicated that solid-liquid extraction was not a practical method of obtaining or preparing organics for "worst case" fuel cell water simulant. Five organics, namely, (1) toluene, (2) propyl acetate, (3) sodium lauryl sulfate, (4) isobutyl methyl ketone, and (5) xylenol, were identified as probable extractables from the nonmetallics; these compounds were selected for use in "worst case" fuel cell water simulant (pp 2-4 to 2-6).

D. Adsorption isotherm tests were performed with the five aforementioned organics and preselected activated charcoals. Test results showed that a mixed bed of charcoals, composed of 2 parts by weight Union Carbide's Columbia and 3 parts by weight Westvaco"s Nuchar, has a capacity of 350 mg of COD per gram of charcoal at equilibrium for a 100 ppm mixture (equivalent COD of 140 ppm) of the five organics (pp 2-6 to 2-11).

1.3.2 Breadboard Tests

A. Two seven-day (168 hour) Breadboard SMT's were performed with upgraded canister contents. The results of the tests demonstrated improved performance over that experienced under Contract NAS 9-12104. The product water quality was excellent; the pH ranged between 7.0 and 7.1, the specific resistance was always greater than 150,000 ohm-cm, and 95% or more of the organics were removed. The silver ion content of the product was, as expected, above 0.05 ppm, ranging between 0.07 and 0.10 ppm. The inclusion of ion exchange resins in the ACF did remove the chlorides (common ion) from the FCW simulant, and increased the solubility of AgCl by one order of magnitude; the net effect was an increase in silver ion dose in the stored water from approximately 0.1 ppm to approximately 1.0 ppm. It was concluded that partial bypassing of deionized water through the silver bromide column would be required to maintain the dose of silver ions in the product water below 0.05 ppm (pp 4-1 to 4-11).

B. Random vibration tests simulating launch environment showed no effects on chemical performance (pp 4-3 to 4-11).

C. Random vibration and hydraulic testing showed that AgBr fines were produced either as a result of packing the canister or attrition during vibration. It was concluded that a cartridge concept should be utilized to facilitate packing and washing of the silver halide columns, and to eliminate preparation as the mechanism for AgBr fines production (pp 4-3 to 4-8).

1.3.3 PFP Design & Fabrication

A. A Preliminary Flight Prototype system was designed and fabricated to treat "worst case" fuel cell water simulant. The system is an assembly of upgraded breadboard canisters, welded together. The system includes (1) a biological filter, (2) an activated charcoal and ion exchange canister, (3) a silver chloride canister, (4) a deionizer, (5) a silver bromide canister and (6) mock-up instrumentation and circuitry for a pH meter, a silver ion meter and a system delta-pressure transducer (pp 5-1 to 5-12).

B. A new biological filter was designed and fabricated. It contains a filter cartridge, a check valve, a bypass relief valve, and a AgCl column (pp 5-3 to 5-5).

C. A silver chloride cartridge was designed and fabricated to facilitate preparation and washing of the AgCl-glass bead bed (pp 5-5 and 5-7).

D. A silver bromide cartridge was designed and fabricated to facilitate preparation and washing of the AgBr-glass bead bed, to bypass some of the water passing through the canister and to obtain a silver dose of approximately 0.05 ppm in the product water (pp 5-7 and 5-8).

1.3.4 PFP Tests

A. A seven day baseline SMT was performed with the Preliminary Flight Prototype system. The performance of the PFP system was satisfactory and according to predictions; the product water quality was excellent and within all specifications for potability. (pp 6-1 to 6-6).

B. A 0.02 - 0.03 ppm silver ion dose and 21 hours of contact time exhibits bactericidal activity against 10^4 Pseudomonas aeruginosa and/or Type IIIa bacteria (pp 6-3 and 6-6).

C. Random vibration testing of the PFP hardware showed no significant detrimental effects (p 6-3).

D. Random vibration and hydraulic testing of the PFP hardware showed no wash-out of AgBr fines (pp 6-3, 6-8 and 6-6).

E. An eighteen day SMT was performed with the PFP system which included injection of bacteria at possible points of entry during the first ten days. The performance of the system was satisfactory; the product water quality was excellent and within all potability specifications for the first 13 days. On days 14 to 18, the product water pH was below 6.0. The silver ion content of the stored water was approximately 1 ppm; this silver ion dose was bactericidal against $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa and/or Type IIIa, and reduced Bacillus subtilis spores by three orders of magnitude in 21 hours (pp 6-8 to 6-17).

1.3.5 Tests without Chlorides in the Simulant

Three tests were performed with a modified PFP system processing simulated Pratt & Whitney fuel cell water. The components used in these tests are: (1) a one-micron particulate filter, (2) a silver chloride column, and (3) a deionizer with a partial bypass (pp 7-1 to 7-18).

A. A seven day SMT was performed with "worst case" Pratt & Whitney type fuel cell water simulant containing 100 ppm organics. The product water pH was within specifications during the first four days; approximately 31.6% of the theoretical ion exchange capacity was expended before pH breakthrough. Approximately 60% of the organics were removed during the first three days and virtually none

thereafter. The silver ion concentration was approximately 1.1 ppm in the stored water and approximately 0.05 ppm in the product water (pp 7-5 to 7-9).

B. An eight day SMT was performed with "mid case" Pratt & Whitney type fuel cell water simulant containing 50 ppm organics. The product water pH was within specifications during the first six days; approximately 32.9% of the theoretical ion exchange capacity was expended before pH breakthrough. Approximately 70 - 80 % of the organics were removed during the first three days and virtually none thereafter. The silver ion concentrations were approximately 1 ppm in the stored water and 0.04 - 0.05 ppm in the product water (pp 7-9 to 7-15).

C. An eleven day SMT was performed with "low case" Pratt & Whitney type fuel cell water simulant containing 10 ppm organics. The product water pH was within specifications during the first ten days. Approximately 27.5% of the theoretical ion exchange capacity was expended before pH breakthrough. No discernable amount of organics were removed. The silver ion concentrations were approximately 1 ppm in the stored water and 0.05 ppm in the product water (pp 7-14 and 7-16 to 7-22).

D. An in-depth, one-micron filter does not exclude bacteria and particulates effectively (pp 7-5,7-8,7-9,7-12,7-15 and 7-21).

E. A 1 ppm silver ion dose was bactericidal against $3 \pm 1 \times 10^{10}$ (i.e., $3 \pm 1 \times 10^{5}$/ml) Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less (pp 7-8, 7-15, and 7-21).

F. A 1 ppm silver ion dose at ambient temperatures reduced Bacillus subtilis counts by up to 5 orders of magnitude in 24 hours (pp 7-8, 7-15 and 7-21).

G. A 0.050 ppm residual silver ion dose was more efficacious at elevated temperatures, 330 - 336°K (135 - 145°F) than at lower temperatures, 279 - 282°K (42 - 48°F). When breakthrough or contamination of Bacillus subtilis occurred, their counts at the hot water outlet were lower than at the cold water outlet (pp 7-8, 7-15 and 7-21).

1.3.6 Tests with Chlorides in the Simulant

Two tests were performed with a modified PFP system processing General Electric type fuel cell water simulant. The components of this system are: (1) a biological filter, (2) an ion exchange column, (3) a silver chloride column, and (4) a deionizer with a partial bypass (pp 7-18 and 7-23 to 7-42).

A. An eight day SMT was performed with "worst case" General Electric type fuel cell water simulant containing 100 ppm organics. The product water pH was within specifications during the first seven days; approximately 25.2% of the theoretical ion exchange capacity was expended before pH breakthrough. Approximately 60% of the organics were removed during the first five days and thereafter virtually none. The silver ion concentrations were approximately 1 ppm in the stored water and approximately 0.05 ppm in the product water (pp 7-26 to 7-32).

B. A twenty day SMT was performed with "low case" General Electric type fuel cell water simulant containing 10 ppm organics. The product water pH was within specifications during the first eighteen days; approximately 21.6% of the theoretical ion exchange capacity was expended before pH breakthrough. A significant amount of organics were removed. The silver concentrations were approximately 1 ppm in the stored water and approximately 0.05 ppm in the product water during the first 13 days; thereafter the silver ion concentration decreased daily as the absorptive capacity of the ion exchange column upstream of the AgCl canister diminished from 0.9 ppm on day 14 to 0.16 ppm on day 20 in the stored water, and from 0.05 ppm on day 14 to 0.024 ppm on day 20 in the product water (pp 7-32 to 7-42).

C. The biological filter excluded bacteria and particulates effectively (pp 7-31 and 7-40 to 7-42).

D. The bactericidal/bacteriostatic effects of a 1.0 and 0.05 ppm silver ion dose were similar to results previously experienced during the PFP Tests and the Extended Tests without chlorides in the simulant (pp 7-31 and 7-40 to 7-42).

1.3.7 AgBr Efficacy Tests

Four tests were performed with a modified PFP system processing anticipated fuel cell water simulant. A AgBr column with a partial bypass was the only component employed (pp 7-43 to 7-51).

A. Two tests were performed with anticipated fuel cell water simulant containing 10 ppm organics. A 0.05 ppm silver ion dose was bactericidal against $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa and/or Type IIIa in 15 minutes or less (pp 7-46 to 7-48).

B. Two tests were performed with anticipated fuel cell water simulant containing 100 ppm organics. A 0.05 ppm silver ion dose was bactericidal against $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml, Pseudomonas aeruginosa and/or Type IIIa in 15 minutes or less (pp 7-46, 7-49, 7-50 and 7-51).

1.3.7 Odor and Taste Tests

A. Anticipated fuel cell water simulant with 10 ppm organics (2 ppm each of toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone, and xylenol) has an Odor No. 8 and a Taste No. 10 (p 7-50).

B. Product waters from the Extended test with "low case" General Electric type fuel cell water simulant containing 10 ppm organics (i.e., Extended Test No. 5) had the following odors and tastes (p 7-50).

Test Day	Odor No.	Taste No.
1	8	3
20	12	---

C. It is concluded that none of the product waters obtained during the Extended Tests (with and without chlorides) satisfied the potability criteria for Odor (No. 3) and Taste (No. 3).

1.4 Recommendations

This report shows that a 0.050 ppm silver ion dose, passively added to fuel cell water simulant was bactericidal against the two types of bacteria previously found in Apollo water systems; $3 \pm 1 \times 10^9$ or $5 \pm 1 \times 10^4$/ml Pseudomonas aeruginosa and/or Type IIIa cells were killed in fifteen (15) minutes or less. All of the components used in the Preliminary Flight Prototype (PFP) system designed to treat "worst case" fuel cell water simulant proved to be reliable, have sufficiently low resistance to flow and have the desired useful life. However, the components used in the modified PFP systems to treat various grades of Pratt & Whitney and General Electric fuel cell water simulant had two shortcomings; namely, (1) the in-depth one micron particulate filter did not exclude bacteria and particulates effectively, and (2) the ion exchange resins did not remove the organics adequately to satisfy the potability specifications for odor and taste.

It was demonstrated that only a filter and silver bromide column were required to treat "anticipated" fuel cell water (i.e., the new baseline fuel cell water composition for the Space Shuttle). However, even if the fuel cell water complies with the chemical limits for potability, it may have objectionable odor and taste. The experimental data collected and the requirements indicate that as a minimum the Space Shuttle water treatment system should include (1) a biological filter, (2) an activated charcoal bed and (3) a silver bromide bed.

It is recommended that NASA continue the development of a system utilizing silver ions as the bactericide. The next logical step in the development is to design, fabricate and evaluate an advanced prototype silver ion water bactericide system. The advanced prototype must incorporate the flight characteristics of minimum weight, low pressure drop, maintainability and compactness. The advanced prototype system should be exposed to simulated Shuttle launch environments to demonstrate hardware integrity and maturity, and following vibration exposure the advanced prototype system should be life tested under simulated Shuttle 7-day mission conditions.

PRELIMINARY TESTING

Preliminary testing was performed to resolve the problems which arose under Contract NAS 9-12104. These problems included low product water pH, high TOC measurements, and low Ag^+ concentration in the stored water.

2.1 Ion Exchange Resins Investigations

Ion exchange resins were investigated to rectify the low pH problem encountered under Contract NAS 9-12104. An industrial survey, literature study and development tests were performed. The problem was satisfactorily resolved by providing strong base anion exchange capacity (Amberlite IRA-402) to prevent the breakthrough of acids (primarily HF) which were not satisfactorily absorbed by Amberlite IR-45 (a weak base anion exchange resin).

The industrial survey and literature study indicated that a mixed bed configuration would always produce a higher quality effluent; this information eliminated separate bed (conventional or reverse) configurations from further consideration. The survey also indicated that in addition to the various strong base anion exchangers, an intermediate base anionic resin (Rohm & Hass Company's Amberlite IRA-47 or BioRad Laboratory's BioRex 5) was available, which had service temperature capabilities up to 366°K (200°F) and was compatible with the sterilization techniques.

A series of development tests were performed with the breadboard system using "worst case" fuel cell water; the goal was to achieve a pH $\geq$ 7. The results of these tests are summarized in Table 1. The tabulated information shows that increasing the ratio of weak base anion to cation exchanger (Test 2) did not increase the pH over 7, and the use of the intermediate base anion exchanger did not improve the pH over the baseline (Test 1). The results of these tests also indicated that weak and intermediate base anion exchangers do not have the capability to absorb the acidity; therefore, it was concluded that a strong base anion exchanger would have to be employed.

Strong base anion exchangers were used in Tests 4, 5 and 6. The tabulated data shows improvements in pH and adsorption capability. Test bed 4, a commercially available mixture of a strong acid cation exchange resin (Amberlite IR-120) and a strong base anion exchange resin (Amberlite IRA-400) in a one to one equivalent ratio, increased the pH over the baseline, but the goal of a pH > 7 was not achieved. Test 5 shows that increasing the amount of strong base anion to cation exchanger was beneficial. Test 5 results also indicate that the strong base anion exchanger (Amberlite IRA-402) loses some of its capacity as a result of the sterilization cycle (24 hours at 344°K). Test bed 6, a mixture

Table 1 DEIONIZER DEVELOPMENT TESTS

Test 1

Bed: Mixed, 240 ml Amberlite IR-120 & 210 ml Amberlite IR-45
Sterilization: 355°K (180°F) water bath for 18 hrs with 50 ml/min deionized water flushing.

Day	pH	Specific Resistance (megaohm-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	6.0	0.82	---	3	<0.010
2	6.1	0.86	2.0	2	<0.010
3	5.7	0.74	1.6	2	<0.010

Test 2

Bed: Mixed, 165 ml Amberlite IR-120 & 285 ml Amberlite IR-45
Sterlization: 355°K (180°F) water bath for 18 hours with 50 ml/min deionized water flushing.

Day	pH	Specific Resistance (megaohm-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	6.3	0.94	3.0	3	<0.010
2	6.1	1.4	1.6	4	<0.010
3	6.3	1.28	1.6	3	<0.010

Test 3

Bed: Mixed, 260 ml Amberlite IR-120 & 190 ml Amberlite IRA-47
Sterlization: 344°K (160°F) water bath for 24 hours with 50 ml/min deionized water flushing.

Day	pH	Specific Resistance (megaohom-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	5.1	0.24	4.0	4	<0.010
2	4.7	0.09	14.2	11	<0.010
3	4.05	0.02	16.0	2	<0.010

Table 1 (Concluded)

Test 4

Bed: 450 ml Amberlite MB-1 (mixture of Amberlite IR-120 & Amberlite IRA-400)
Sterilization: 344°K (160°F) water bath for 24 hours with 50 ml/min deionized water flushing

Day	pH	Specific Resistance (megaohm-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	6.6	1.26	1.0	2	<0.010
2	6.4	0.98	1.2	9	<0.010
3	6.6	0.88	1.4	7	<0.010

Test 5

Bed: Mixed, 120 ml Amberlite IR-120 & 320 ml Amberlite IRA-402
Sterilization: 344°K (160°F) water bath for 24 hours with 40 ml/min deionized water flushing.

Day	pH	Specific Resistance (megaohm-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	7.6	1.1	1.0	10	<0.010
2	7.6	0.98	1.0	12	<0.010
3	7.5	0.80	1.0	1	<0.010
4	7.4	0.44	1.0	6	<0.010
5	7.3	0.16	1.8	8	<0.010
6	4.8	0.01	12.0	5	<0.010
7	4.1	0.01	18.0	9	<0.010

Test 6

Bed: Mixed, 200 ml Amberlite IR-120, 150 ml Amberlite IRA-402 and 100 ml Amberlite IR-45.
Sterilization: 344°K (160°F) water bath for 24 hours with 40 ml/min deionized water flushing.

Day	pH	Specific Resistance (megaohm-cm)	Total Acidity (ppm)	Total Solids (ppm)	Ag^+ Conc. (ppm)
1	7.8	1.3	1.0	1	<0.010
2	7.6	1.1	1.0	1	<0.010
3	7.5	1.1	1.0	4	<0.010
4	7.5	1.0	1.0	2	<0.010
5	7.5	0.78	1.6	2	<0.010
6	6.2	0.10	4.2	9	<0.010
7	6.0	0.07	5.6	3	<0.010
8	6.0	0.03	8.8	4	<0.010
9	5.3	0.01	8.8	7	<0.010

of weak and strong base anion exchangers, evidenced more acid absorption capability and pH control than test bed 5 which contains only strong base anion exchangers. The maximum recommended operating temperature for the strong base anion exchange resins is 333°K (140°F). The tabulated information also shows that the silver ion concentration from the deionizer is below the desired value (0.05 ppm maximum); the strong acid cation exchanger (Amberlite IR-120) is satisfactorily absorbing Ag^+.

A deionizer with the composition of test bed 6 was employed in the design of the Preliminary Flight Prototype System because it performed the best and had satisfactorily withstood the sterilization cycle. It was also decided to place approximately 985 cubic centimeters (60 cubic inches) of this resin mixture in the activated charcoal column to pick up chlorides in the simulant. Removal of the chlorides reduced the common-ion effect on the solubility of the silver chloride. As a result the silver ion concentration in the stored water increased to greater than 1 ppm.

2.2 Activated Charcoal Investigations

Under contract NAS 9-12104 the organic constituent (ethylene glycol) used in the FCW simulant was not readily adsorbed. Inquiries to various suppliers of activated carbon indicated that low molecular weight, soluble organic matter is not very adsorbable. Subsequently General Electric (developer of a fuel cell) informed NASA JSC that ethylene glycol would not be an organic contaminant of fuel cell water. If ethylene glycol was present, the fuel cell would not be in a normal operating condition.

NASA JSC performed extraction tests on various nonmetallics used in the construction of the fuel cell, and concluded that three materials are the primary contributors of the organic contaminants. The nonmetallics were identified as (1) 3M's AF-42 Scotch Brand Weldbond Film, (2) General Electric's RTV-630, and (3) Union Carbide's Polysulfone.

Extraction and decantation tests were performed at ambient and elevated temperatures over a seven day period by CHEMTRIC. The results of these tests are presented in Table 2. The tabulated information shows that the amount of organics extracted each day diminishes with time. The data shows that (1) 3M's AF-42 adhesive film contributes the most organics per unit area, (2) GE's RTV-630 silicone rubber eludes one-third the amount of organic per unit area, and (3) Union Carbide's Polysulfone is the lowest source of organics per unit area. In the fuel cell, only 355 square centimeters (55 square inches) of AF-42 adhesive film are exposed to fuel cell water, whereas, 14,450 square centimeters (2240 square inches) of RTV-630 and 542,000 square centimeters (8400 square inches) of Polysulfone are exposed to fuel cell water. Calculations indicate that to obtain 100 ppm of total organics in the FCW simulant (63 liters/day) for the future bread-

Table 2 NONMETALLIC EXTRACTION TESTS

Ambient Temperature

Quantity of Organic Extracted μg COD/cm^2 /day

Day	AF-42	RTV-630	Polysulfone
1	249	5	20
2	28	5	20
3	14	5	20
4	6	5	20
5	2	5	20
6	2	5	20
7	2	5	20
Average	47	5	20

Elevated Temperature

Quantity of Organic Extracted μg COD/cm^2 /day

Day	AF-42[1]	RTV-630[2]	Polysulfone[3]
1	360	5	20
2	110	48	20
3	70	121	20
4	28	5	20
5	14	5	20
6	2	5	20
7	2	5	20
Average	84	28	20

1 Elevated to 344°K (160°F) for a 1 hour period daily
2 Elevated to 366°K (200°F) for a 1 hour period daily
3 Elevated to maximum of 372°K (210°F) for a 1 hour period days 3 - 7.

board and PFP simulated mission tests (35 days) would require the preparation, processing and extraction of over 92.9 square meters (1000 square feet) of adhesive film, RTV-630 silicone rubber film, and/or polysulfone sheet material. This approach to obtain representative organic contaminants was deemed not practical.

The organics extracted from 3M's AF-42 adhesive film and GE's RTV-630 were subjected to activated charcoal adsorption tests. Figures 3 and 4 present the adsorption isotherms of two different activated charcoals. The data shows that Westvaco's Nuchar brand of activated charcoal has more adsorptive capacity for the extractables from both the AF-42 adhesive film and RTV-630 silicone rubber than Witco's 718 brand of activated charcoal.

Since solid-liquid extraction was not a practical approach to generate 100 ppm of organics and because NASA JSC desired 100 ppm organics at all times in the "worst case" PCW simulant, an industrial survey and literature study was performed to determine the probable extractables from Nylon, Teflon, RTV-630 silicone rubber, Polysulfone, and epoxy adhesive films. Five organics were identified as probable extractables from the aforementioned nonmetallics. They are as follows: (1) toluene, (2) propyl acetate, (3) sodium lauryl sulfate, (4) isobutyl methyl ketone, and (5) xylenol.

Adsorption isotherm tests were performed with the five previously mentioned organics at 100 ppm concentration and with two different types of activated charcoal. Figures 5 and 6 present the adsorption isotherms for Westvaco's Nuchar activated charcoal and Union Carbide's Columbia activated charcoal. The plots show that Union Carbide's Columbia brand of activated charcoal has more adsorptive capacity for toluene and propyl acetate, whereas, Westvaco's Nuchar brand of activated charcoal has more adsorptive capacity for sodium lauryl sulfate, isobutyl methyl ketone and xylenol.

An adsorption isotherm test was performed with the five organics (toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone, and xylenol) each at 20 ppm concentration and with a mixed bed of activated charcoals composed of 2 parts by weight Union Carbide's Columbia and 3 parts by weight Westvaco's Nuchar to determine minimum activated carbon requirements. Figure 7 presents the adsorption isotherm. The plot shows that the mixture of activated charcoals has a capacity of 350 mg of COD per gram of charcoal or 35.0% at equilibrium.

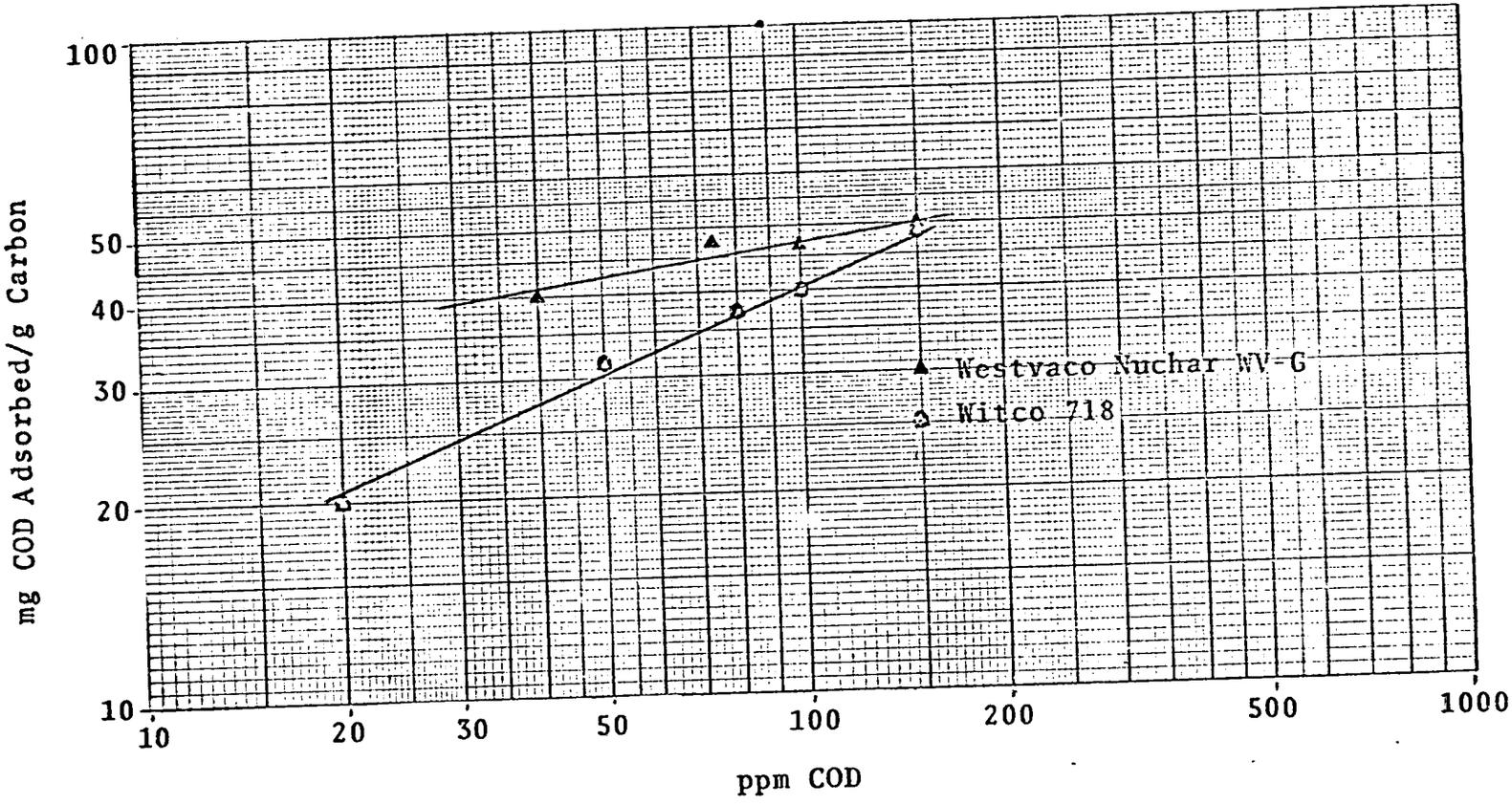

Figure 3 ADSORPTION OF AF-42 EXTRACTABLES

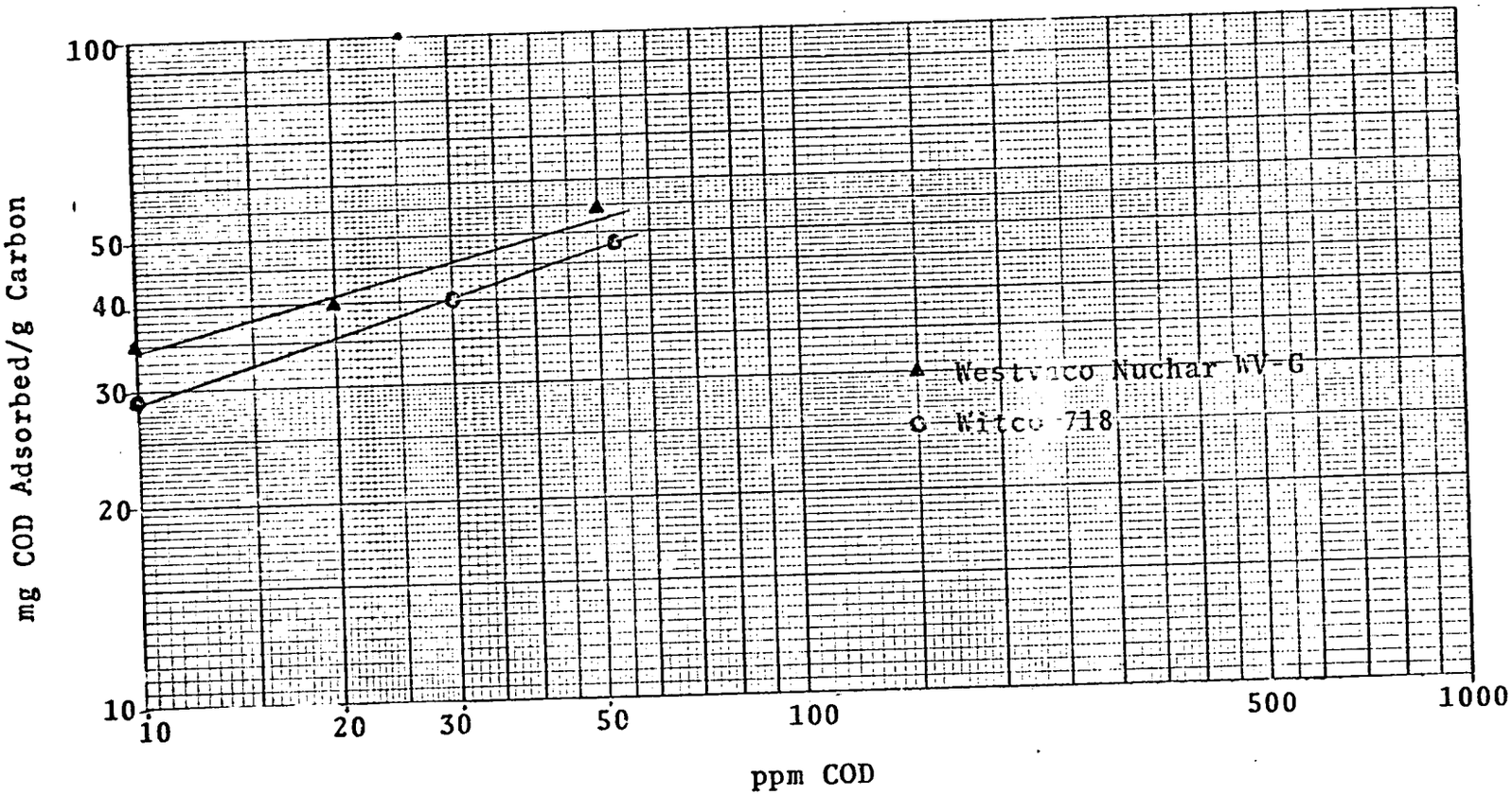

Figure 4 ADSORPTION OF RTV-630 EXTRACTABLES

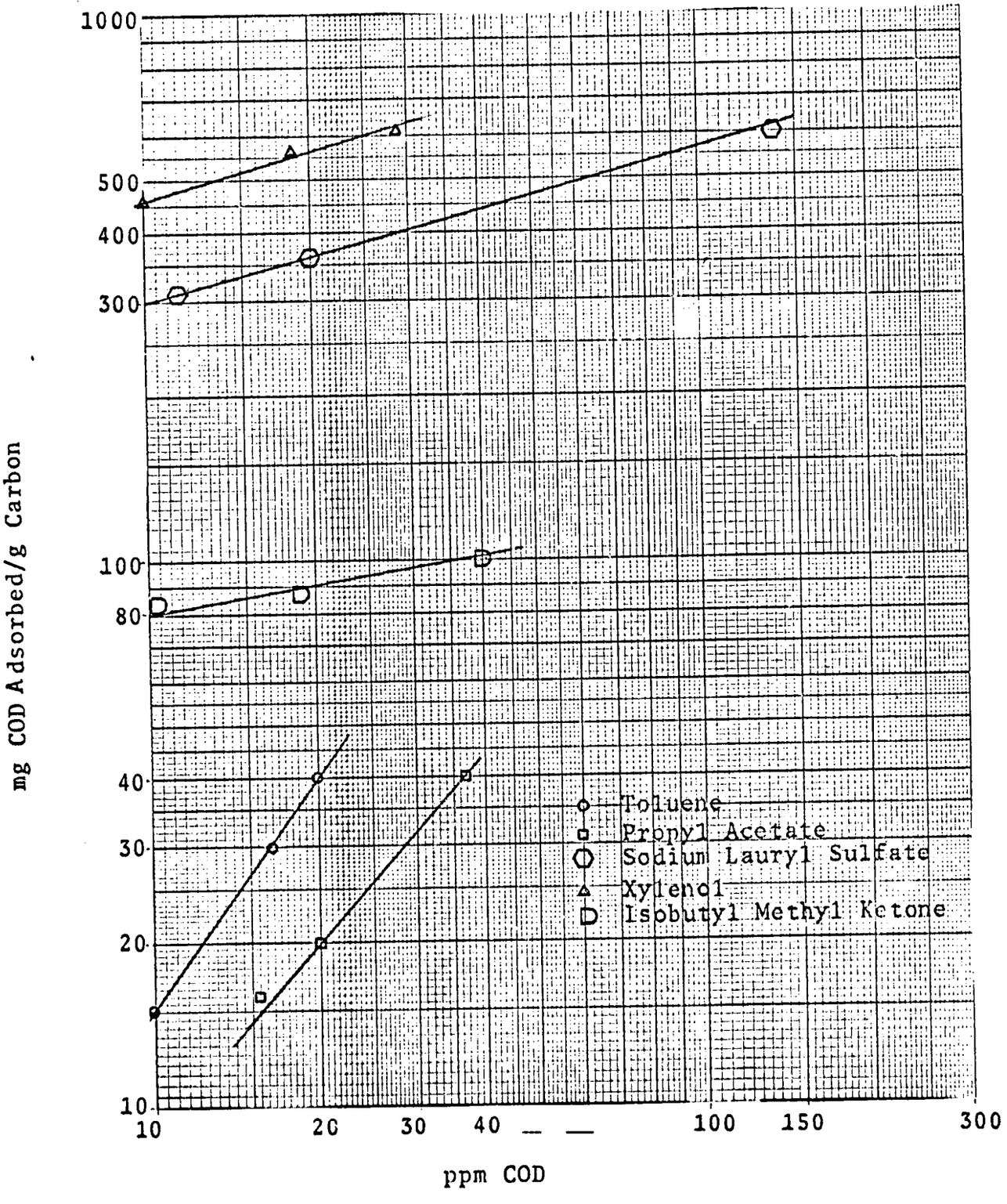

Figure 5 WESTVACO NUCHAR WV-G ADSORPTION OF ORGANIC SIMULANTS

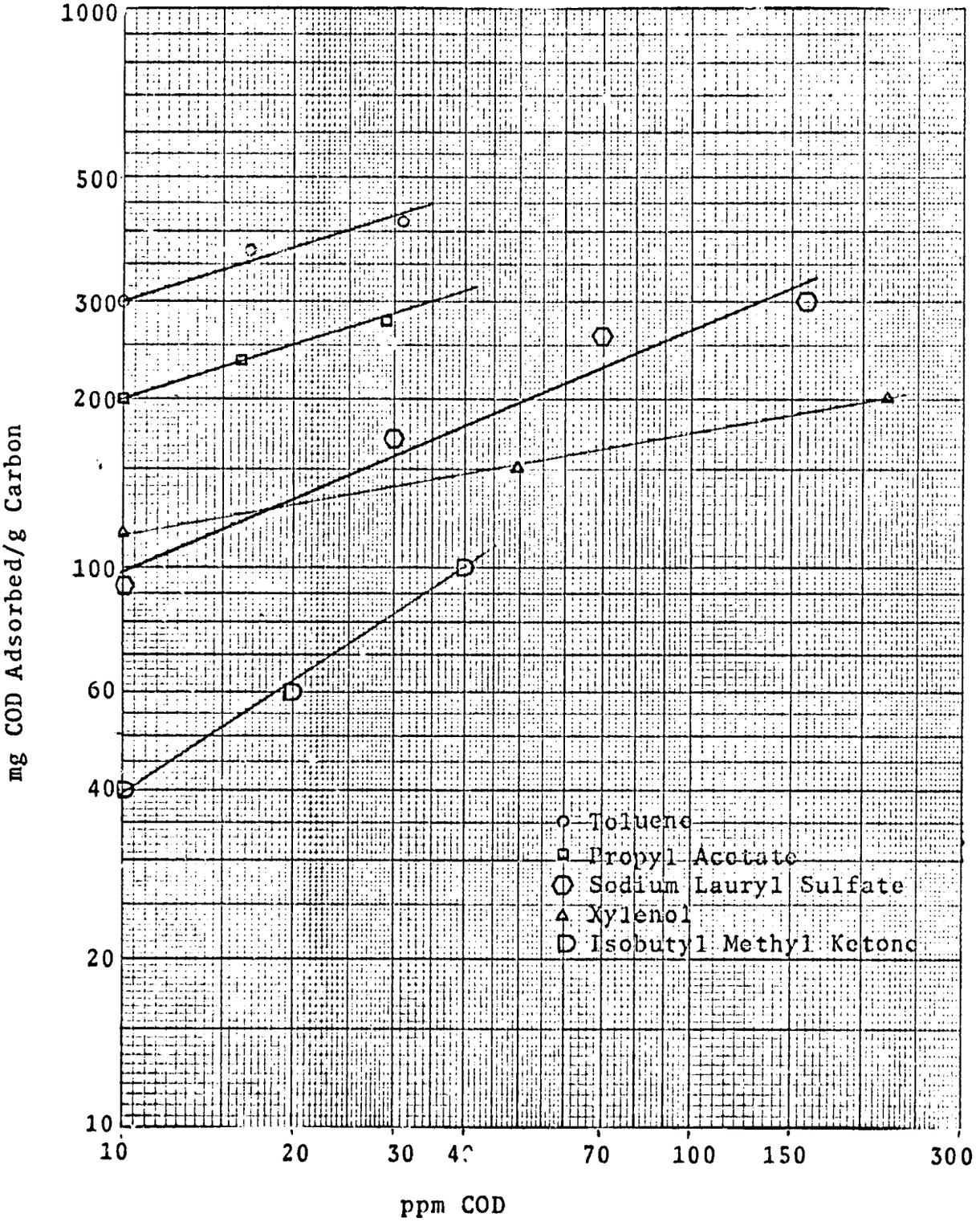

Figure 6 UNION CARBIDE. COLUMBIA LCJ ADSORPTION OF ORGANIC SIMULANTS

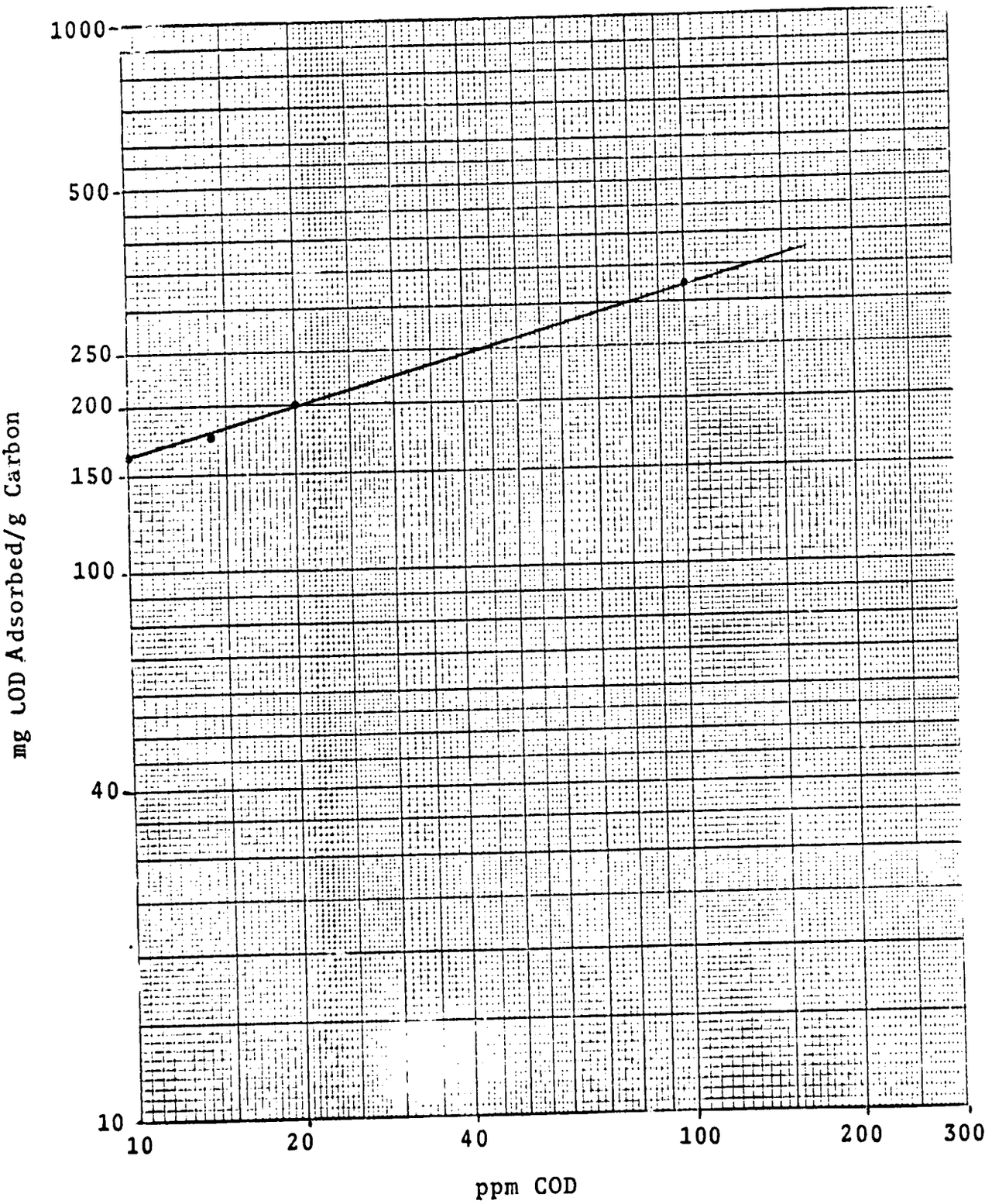

Figure 7 ADSORPTION OF ORGANIC SIMULANT MIXTURE BY MIXED CHARCOALS

2.3 Conclusions

The Preliminary Testing proved very productive. The three problem areas of contract NAS 9-12104 were resolved. The product water pH was found to be within the 6.0 - 8.0 potability level for at least seven days. The low concentration of silver ions in the stored water was rectified. Ion exchange resin placed upstream of the silver chloride column allowed the solubility of the silver to increase by an order of magnitude. Finally, more representative organic constituents of the fuel cell water were defined and a proper mixture of activated charcoals was found to remove at least 95% of these organics.

TEST PROCEDURES & METHODS

3.1 Test Routine

3.1.1 Water Management

The daily test routine was dictated in part by the need to accomplish sampling and simulant preparation within an 8-hour day (single shift). The specific simulant influent flow rates, i.e., 3.95 liters/hr and 1.98 liters/hr (8.7 lb/hr and 4.35 lb/hr), were used for the time durations specified below.

An SMT was initiated at mid-day. The initial simulant input rate was set at 4 liters/hr (approximately equal to 8.7 lb/hr) and maintained for four hours. At this time, the rate was reduced to 2 liters/hr (approximately equal to 4.35 lb/hr) and maintained for sixteen hours. During the 16-hour period, the system was unattended except for brief status checks. At the beginning of the 21st hour, the simulant input rate was increased to 4 liters/hr. Product water draw-off and simulant/product water flow regimen were followed on each day of each SMT.

The simulant and product water flow rates were verified by graduated reservoirs and elapsed time measurements. Instantaneous read-out of the product water flow rate was provided by a calibrated flow meter.

System pressure was controlled by the pressurant gas regulator. An operating pressure of 231,000 Newtons per square meter (33.5 psig) was necessary for a water delivery rate of 22.7 liter/hr (50 lb/hr) with 207,000 Newtons per square meter (30 psi) head.

The bactericide system was challenged by injecting known quantities of viable bacteria into the system at selected locations. Bacteria were injected once each day at a single location.

3.1.2 Water Sampling

An important objective of the test program was the evaluation of individual component performance as well as overall system performance. To accomplish both evaluations, sampling and subsequent analysis of water at intermediate stages in the system had to be performed in addition to final product water sampling analysis. Such activity was conducted uniformly in each SMT to insure a common basis of comparison.

3.1.2.1 Intermediate Sampling and Analyses

This effort was primarily to assess the silver dose level achieved by the AgCl column and to assess the performance of the activated charcoal filter.

Samples were taken twice each day (4 hours and 21 hours after start-up) from the septum downstream of the storage tank. The metering pump was stopped for sampling so that only tank contents were sampled. All samples were taken aseptically. Two separate 500 ml samples were taken at each time, thereby providing individual samples for chemical and bacteriologic analysis. Five milliliters of 1/10 normal sodium thiosulfate were added to the 500 ml biological sample immediately after sampling to arrest the bactericidal action of silver ions.

3.1.2.2 Final Product Water Analyses

Sampling of the final product water was performed at the end of each test day when the product water was being drained from the system. Grab samples were taken in the first, second,and third hours of hot and cold water draw-off for in-house analyses, primarily biological. Chemical analyses were performed on the accumulated product water each day.

The first 500 ml of product water drained was taken from the hot water outlet valve. Half of the sample was used for biological analyses while the remainder was used for silver analyses and key performance characteristic/determination.

The first 500 ml of product water drained from the cold water outlet valve was sampled. Again, half of the sample was used for biological analyses while the rest was used for chemical analyses.

The second hour grab samples from each outlet valve were used exclusively for biological analyses (plate counts). All grab samples were taken in sterile bottles directly from the hot and cold outlet valve.

Samples of product water were taken directly from the reservoir after all of the product water had been drained off. The analyses were performed on the product water each day. In addition, numerous samples were shipped to NASA JSC for complete analysis on selected days.

3.2 Simulant Definition

Duplication of the particulate load could not be achieved without significant departure from the stated contaminant content. To duplicate the particle load, more than 1000 ppm of various sized particles would have to be added. CHEMTRIC approximated the particulate contamination requirements by the following:

1. Increased the silica content from 20 ppm to 100. A 250 mesh, silica powder provides particles in the 50 to 100 micron range.

2. Relied on the added bacteria (10,000, 1 to 2 micron particles per 100 ml) to simulate particles at the low end of the particle size spectrum.

3. The specified alkalinity (greater than 30 ppm calcium carbonate) and the specified pH range were incompatible without the presence of alkaline buffers such as carbonates and phosphates; such anions were not included in the worst case constituent tabulation. The problem was further compounded by the fact that many of the metals form (1) highly insoluble carbonate and/or phosphate salts, and (2) highly insoluble hydroxides in solutions with alkaline pH values. The problem was really a question of elimination of either the metallic elements or the alkalinity requirement. CHEMTRIC recommended that the metallic elements be retained. The pH of the FCW simulant was adjusted by the addition of a standardized alkaline solution (sodium hydroxide) to the specified pH range.

4. Five organics previously identified as probable extractables from the non-metallic construction materials of the fuel cell (toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone, and xylenol) were used in equal concentrations (20 ppm each) to provide the 100 ppm organic load.

Except for the deviations noted above, all of the constituents specified were included in the FCW simulant. The constituents along with their respective concentrations are listed in Table 3.

3.3 Chemical Analyses & Methods

This analytical effort was carried out in-house and at NASA JSC. Standard methodology was employed in all analyses.

Table 3 WORST CASE FCW SIMULANT COMPOSITION

Cationic Species	Concentration (ppm)
Cadmium	0.01
Copper	1.00
Iron	0.30
Lead	0.05
Magnesium	0.17
Mercury	0.005
Nickel	0.05
Platinum	0.05
Potassium	0.54
Sodium	3.30
Titanium	0.20
Zinc	5.00
Anionic Species	
Chloride	8.1
Chromate	0.1 (Cr^{+6} = .05)
Fluoride	1.6
Nitrate	0.04
Selenite	0.08 (Se = .05)
Sulfate	6.5
Particulate	
Silica (50 - 100 μ)	100
Bacteria (1 - 10 μ)	100,000/liter
Other	
Total Solids	250
Total Organics	100
pH (pH units)	6.0 - 8.0

The analytical methods employed at NASA JSC are described in detail in Document No. CSD-A-726 (Procedure Manual for Water Analysis). The procedures contained in the above manual are based on the procedures contained in the Standard Methods* text or on superior instrumental methods (e.g., atomic absorption).

The chemical analyses were performed in-house using the following methodology.

(1) Specific Resistance

(a) Method - Standard Methods text, pages 323 - 327

(b) Instrument - YSI Model #31, Conductivity Bridge

(c) Accuracy - ± 1% in range of 2 ohms to 2 megaohms

(2) pH

(a) Method - Standard Methods text, pages 276 - 281

(b) Instrument - Corning Model 7 pH meter

(c) Accuracy - ± 0.05 pH (relative)

(3) Turbidity

(a) Method - Nephelometric as per instrument manufacturer's manual

(b) Instrument - Hach Chemical Co., Model No. 2100 A laboratory turbidimeter

(c) Accuracy - ± 2% of full scale

(4) Total Solids

(a) Method - Gravimetric as per Standard Methods text, pages 535 - 541

(b) Instrument - None

(c) Accuracy - ± 5%

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* Standard Methods for the Examination of Water and Waste Water, 13th Ed., APHA, AWWA, WPCF, Washington, D.C. (1971)

(5) Chloride

(a) Method - Titrimetric, mercuric nitrate method as per Standard Methods text, pages 95 - 99

(b) Instrument - None

(c) Accuracy - ± 4 ppm

(6) Silver

(a) Method - Atomic absorption

(b) Instrument - Perkin-Elmer Model 103, Atomic Absorption Spectrophotometer

(c) Accuracy - ± 0.2%

(7) COD

(a) Method - Standard Methods text, pages 495 - 499

(b) Instrument - None

(c) Accuracy - ± 2 ppm

(8) Acidity

(a) Method - Standard Methods text, pages 50 - 52

(b) Instrument - None

(c) Accuracy - ± 1 ppm

(9) Alkalinity

(a) Method - Standard Methods text, pages 52 - 56

(b) Instrument - None

(c) Accuracy - ± 1 ppm

3.4 Bacteriologic Analyses & Methods

The methodology for culturing the test bacteria, preparing bacteria challenge doses, and analyzing water are presented in the following discussions. Standard techniques were employed.

The test bacteria were obtained as follows:

(1) Type IIIa from the National Center for Disease Control, Atlanta, Ga.

(2) Pseudomonas aeruginosa from the American Type Culture Collection - type #14502

(3) Bacillus subtilis from the American Type Culture Collection - type #6633.

3.4.1 Culturing and Dose Preparation

The above cultures were transferred to appropriate media upon receipt. Sub-cultures of the initial transfers were made and after incubation, were refrigerated for future use.

The flavobacterium species and the Pseudomonas species were cultured on APT agar; the same medium was used in the analyses of water samples. The bacillus species were cultured on AK agar #2; as with the other bacteria species, the culturing medium was also used in the analyses of water processed in the SMT and dosed with the bacillus species. Periodic checks of culture purity were made by gram stain, spore stain and streak plate preparation.

The same general procedure was followed in preparing the challenge doses of each of the three test bacteria. However, the bacillus species did require heat treatment to kill off vegetative cells and consequently some special treatment was required.

A correlation between viable cell count and suspension turbidity was established for each test species. This correlation was used subsequently to aid in determining the cell count in the test dose prior to injection into the system. The detailed procedures were as follows:

(1) Inocculate a kolle flask containing 300 ml of the solid nutrient medium and incubate at 309°K (96.8°F) for 48 hours (120 hours for B. subtilis).

(2) Harvest the culture by teasing the agar surface with a wire loop in the presence of 25 ml sterile, phosphate buffered saline (PBS).

(3) Transfer the suspension to a sterile, capped flask containing 25 ml PBS and a quantity of glass beads. The flask was agitated vigorously for 15 minutes.

(4) The above suspension was then decanted into a sterile, capped, centrifuge tube which in turn was centrifuged. The supernatant liquid was decanted off and the cells resuspended in 50 ml PBS and centrifuged again. The cells were then resuspended in 25 ml PBS.

(5) The final cell suspension was then submitted to serial, decade dilution using 10 ml aliquots. Plate counts (Membrane Filter technique) and turbidity readings were made on each of the dilutions. The correlation established between cell count and turbidity values were used in preparation of the challenge doses.

The correlation established above permitted estimation of the cell count in subsequently prepared suspensions without incurring the delay (24 - 48 hours) inherent in plate counts. Subsequent suspensions were prepared by the above procedures up to step 4. An aliquot of the suspension was then subjected to selected dilutions; the turbidity of these dilutions was determined. From the turbidity, the cell count of the suspension was read from the correlation curve for that species.

Once the cell count of the final suspension was known, the challenge dose could be fixed accurately each time. The minimum challenge dose was 10^6 viable cell and/or spores.

The bacillus species was treated in an identical manner as above up to step 4. However, 8 kolle flasks of this species were used and the final suspension resulting from step 4 was combined in a sterile flask. This combined suspension was immersed in a 343°K (158°F) water bath for 30 minutes after heat treatment; the combined suspension was submitted to plate counts (MF technique). The serial dilutions used in the plate counts were submitted to turbidity measurements for reference purposes. The combined suspension served as the stock for all B. subtilis doses.

An aliquot of all challenge doses was submitted to plate count procedures on the day of injection to verify the estimated dose.

3.4.2 Quantitative Analysis

The assay method used for water analysis and analysis of the cell suspensions was the membrane filter tech-

nique. The nutrient media used for culturing the test bacteria was also used in the assay. Sodium thiosulfate (1.0 ml of 0.1 N solution per 100 ml of water) was added to each sample as soon as possible after sampling to arrest the bactericidal action of silver.

The membrane filter method of assay is a standard procedure and need not be described at length. The salient features of the subject application are as follows:

(1) Five hundred ml of samples were filtered.

(2) The filter disc was washed with three 100 ml aliquots of 0.001 N sodium thiosulfate, followed by washing with three 100 ml aliquots of APT broth. Filter discs used in cell suspension assays were washed with APT broth only.

(3) Standard filter disc holders were used (Millipore catalog #XX11-047-00).

(4) Standard filter discs (47 mm diameter) were used; the pore size was 0.22 microns.

(5) The filter discs were placed (rolled) onto the surface of the appropriate agar medium; the petri dishes were sealed with plastic tape and incubated in a humidified incubator.

(6) The above plates were inspected for growth after 24 and 48 hours of incubation.

All water samples were assayed on the day that they were acquired.

3.5 NASA JSC Lab Silver Analyses

Samples of stored water and product water were analyzed for silver content by the JSC Labs. The results of these analyses are presented in Appendix B and compared with the determinations performed by CHEMTRIC. The objective of conducting duplicate analyses was to corroborate the CHEMTRIC analyses and to establish a confidence level in the performance of the components and system under development. The silver analyses by CHEMTRIC were performed on the day the samples were collected; whereas, the silver analyses performed by the JSC Labs were performed several weeks after completion of a test.

In general the results were comparable. However, two types of anomalies were observed. In the more prevalent type of anomaly, the EC3 Lab silver determinations were less than CHEMTRIC's determination. The Ellington DD6 Lab silver analyses confirmed the differences. Shelf tests indicated that recycled polypropylene plastic sampling bottles were depleting the silver concentration. The recycled plastic bottles occasionally contained biologically contaminated water, and the water to be discarded was dosed with iodine before discarding down the drain. It was concluded that iodine was absorbed by the polypropylene plastic and subsequently reacted with the silver ions during shipment and reduced the silver ion concentration. This problem was eliminated by immediately transferring water samples to new plastic bottles if samples were collected in recycled bottles and eventually discarding all of the old recycled polypropylene bottles.

In the lesser type of anomaly the EC3 Lab silver determinations were greater than CHEMTRIC's determinations. It appears that contaminants were being extracted from some of the polyethylene plastic shipping bottles and were interferring with the analysis, since analytical corroboration was achieved on duplicate samples shipped in another polyethylene bottle. However, a more detailed investigation of this anomaly was not conducted because the source of contaminants was attributed to some polyethylene bottles of random quality.

BREADBOARD TESTS

Two seven-day (168 hour) simulated mission tests were performed with the upgraded canister designs (contents) and processing schemes. The objective of these tests was to demonstrate improved system performance and that no performance degradation would occur because of the random vibrating testing.

4.1 Test Apparatus

Figure 8 shows the arrangement of canisters and ancillary components in the breadboard tests. The components that define the processing system, in the order of their use are as follows: (1) biological filter, (2) activated charcoal and ion exchange filter, (3) silver chloride column, (4) deionizer, and (5) silver bromide column. The hardware (canisters) and ancillary components were the same as developed under Contracts NAS 9-12104. The activated charcoal filter and the deionizer contents were upgraded; the other components remained unchanged.

The breadboard canisters were packed and prepared in accordance with the information developed during the preliminary investigations of ion exchange resins and activated charcoals. The activated charcoal canister was packed with 1970 cm^3 (120 in^3) of mixed activated charcoals and 885 cm^3 (54 in^3) of mixed ion exchange resins. The mixed activated charcoal bed was composed of 1180 cm^3 (71.8 in^3) of Westvaco Nuchar WV-G and 790 cm^3 (48.2 in^3) of Union Carbide Columbia LCJ. The ion exchange bed was composed of a mixture of 394 cm^3 (24.1 in^3) of Amberlite IR-120, 295 cm^3 (18.0 in^3) of Amberlite IRA-402, and 196 cm^3 (11.9 in^3) of Amberlite IR-45.

The deionizer was packed with 450 cm^3 (27.4 in^3) of mixed ion exchange resins. The deionizer bed was composed of 200 cm^3 (12.2 in^3) of Amberlite IR-120, 150 cm^3 (9.1 in^3) of Amberlite IRA-402, and cm^3 (6.1 in^3) of Amberlite IR-45.

Pall Trinity Micro Corporation's housing P/N MCS 1001G16 and filter cartridge P/N MCY 1001UR was the biological filter used in the Breadboard Tests. The silver chloride and the silver bromide canisters were each packed with 218 cm^3 (13.3 in^3) of a mixture of their respective silver halide and glass beads, in a ratio of 1 part silver salt to 1.25 parts of glass beads.

The deionizer canister and the canister containing the activated charcoals and ion exchange resins were sterilized at 344°K (160°F) for 24 hours prior to use.

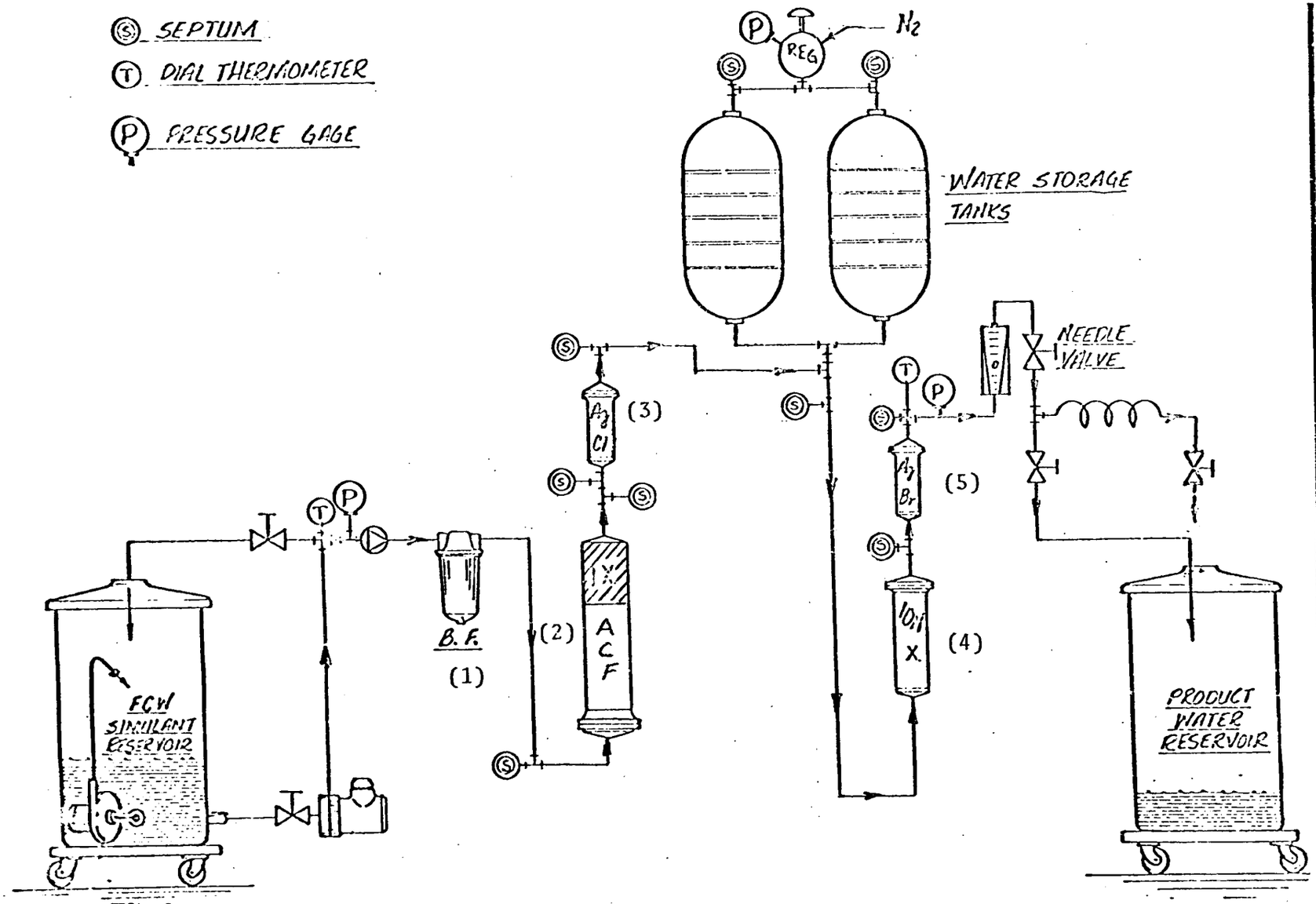

Figure 8 FLOW SCHEMATIC FOR BREADBOARD TESTS

4.2 Breadboard Test No. 1 - Results & Discussion

A seven-day simulated mission test was performed during the period June 20 to June 26, 1972. The objective was to demonstrate improved system performance.

Table 4 lists the daily water quality characteristics of the first breadboard test while processing "worst case" fuel cell water simulant. Tabulated key characteristics indicate the performance of the upgraded breadboard potable water bactericide system was satisfactory and according to predictions. The product water quality was excellent. The pH ranged between 7.0 and 7.1, the specific resistance was always greater than 150,000 ohm-cm, and 97% or more of the organics were removed. The silver ion content of the product water, as expected, was above 0.05 ppm, ranging between 0.07 and 0.10 ppm. The inclusion of ion exchange resins in the ACF did remove the chlorides from the FCW simulant and increased the solubility of Ag Cl. The net effect of performing ion exchange upstream of the AgCl column was an increase in the silver ion dose by an order of magnitude over that observed at ambient temperatures under contract NAS 9-12104.

4.3 Random Vibration Testing

Fixtures to hold the breadboard canisters during the vibration tests were fabricated. The canisters were assembled together with brackets to a mounting plate so that all canisters were exposed to vibration simultaneously.

The assembly was then subjected to the random vibrations specified in Section 1.2 at the Inland Testing Laboratories, Inc., Morton Grove, Illinois. The vibration tests were witnessed by cognizant CHEMTRIC personnel and the NASA JSC Technical Monitor.

4.3.1 External Examination

Visual examination of the canisters after the vibration tests revealed no evidence of any physical damage. A report, Test Report No. 1392-1, prepared by the Inland Testing Laboratories is included in the Appendix C of this report.

4.3.2 Flow Resistance of Canisters - Hydraulic Examination

The operating pressure drop characteristics of the individual canisters were determined three times; namely, pre-vibration, post-vibration, and post second breadboard test. Figures 9 and 10 present the results of the three tests.

Table 4 BREADBOARD TEST No.1 WATER QUALITY CHARACTERISTICS

Test Day & Sample	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)	Count
Day No.1										
Simulant	4.4	24.0	15.2	140	8.2	15.0	0.0	23.1	<0.01	- - -
Stored 4th*	7.1	185.0	0.06	10	<1.0	<1.0	4.0	2.7	0.95	- - -
Stored 21st*	7.1	250.0	0.50	10	<1.0	<1.0	3.5	6.3	0.90	Sterile
Deionizer	7.1	1000.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	870.0	0.05	<5	<1.0	<1.0	2.5	4.3	0.10	Sterile
Day No.2										
Simulant	6.6	21.0	14.0	140	8.2	2.6	6.0	15.5	<0.01	- - -
Stored 4th*	7.1	250.0	0.02	10	<1.0	<1.0	2.0	4.9	0.90	- - -
Stored 21st*	7.1	320.0	0.01	10	<1.0	<1.0	2.0	2.0	1.00	Sterile
Deionizer	7.1	910.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	770.0	0.02	<5	<1.0	<1.0	3.0	0.4	0.10	Sterile
Day No.3										
Simulant	6.6	22.5	15.0	150	8.2	2.0	6.0	21.4	<0.01	- - -
Stored 4th*	7.1	320.0	0.03	10	<1.0	<1.0	<1.0	3.6	1.00	- - -
Stored 21st*	7.1	335.0	0.02	10	<1.0	<1.0	<1.0	5.1	0.85	Sterile
Deionizer	7.1	1300.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	750.0	0.03	<5	<1.0	<1.0	<1.0	0.3	0.10	Sterile
Day No.4										
Simulant	6.6	22.5	15.5	140	8.2	1.6	6.0	14.6	<0.01	- - -
Stored 4th*	7.1	330.0	0.03	10	<1.0	<1.0	<1.0	2.8	1.08	- - -
Stored 21st*	7.1	340.0	0.02	10	<1.0	<1.0	<1.0	3.4	1.30	Sterile
Deionizer	7.1	1280.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	870.0	0.02	<5	<1.0	<1.0	<1.0	0.3	0.10	Sterile

Dashes indicate no analyses performed
* Denotes Hour

Table 4 Concluded

Test Day & Sample	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)	Count
Day No.5										
Simulant	6.6	22.2	15.0	140	8.2	2.4	6.5	14.8	<0.01	- - -
Stored 4th*	6.9	330.0	0.05	10	<1.0	<1.0	<1.0	2.2	1.00	- - -
Stored 21st*	6.9	340.0	0.05	10	<1.0	<1.0	<1.0	1.4	0.95	Sterile
Deionizer	7.1	1170.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	630.0	0.02	<5	<1.0	<1.0	<1.0	0.2	0.10	Sterile
Day No.6										
Simulant	6.5	22.0	15.0	140	8.2	2.0	4.0	15.6	<0.01	- - -
Stored 4th*	6.9	310.0	0.08	10	<1.0	<1.0	<1.0	3.1	0.96	- - -
Stored 21st*	7.0	370.0	0.07	10	<1.0	<1.0	<1.0	3.6	1.02	Sterile
Deionizer	7.1	650.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	600.0	0.03	<5	<1.0	<1.0	<1.0	0.9	0.07	Sterile
Day No.7										
Simulant	6.5	21.5	10.4	140	8.2	2.0	6.0	15.8	<0.01	- - -
Stored 4th*	6.7	350.0	0.08	30	<1.0	<1.0	2.0	0.8	0.92	- - -
Stored 21st*	6.8	310.0	0.04	30	<1.0	<1.0	2.5	1.1	0.96	Sterile
Deionizer	7.0	800.0	- -	10	- -	- -	- -	- -	<0.01	- - -
Product	7.0	160.0	0.04	10	<1.0	<1.0	<1.0	0.2	0.07	Sterile

Dashes indicate no analyses performed
* Denotes Hour

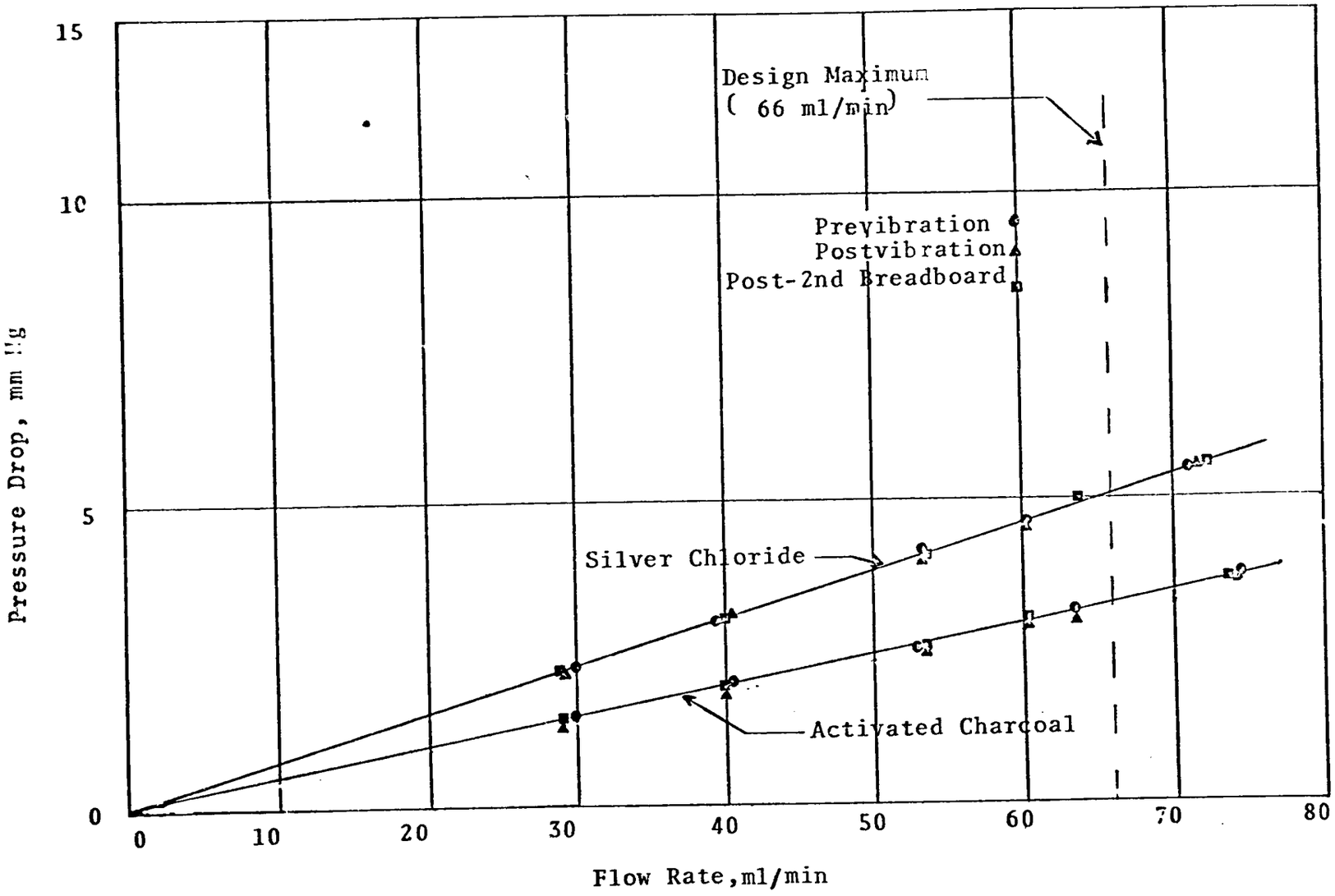

Figure 9 FLOW RESISTANCE OF SILVER CHLORIDE COLUMN AND ACTIVATED CARBON FILTER

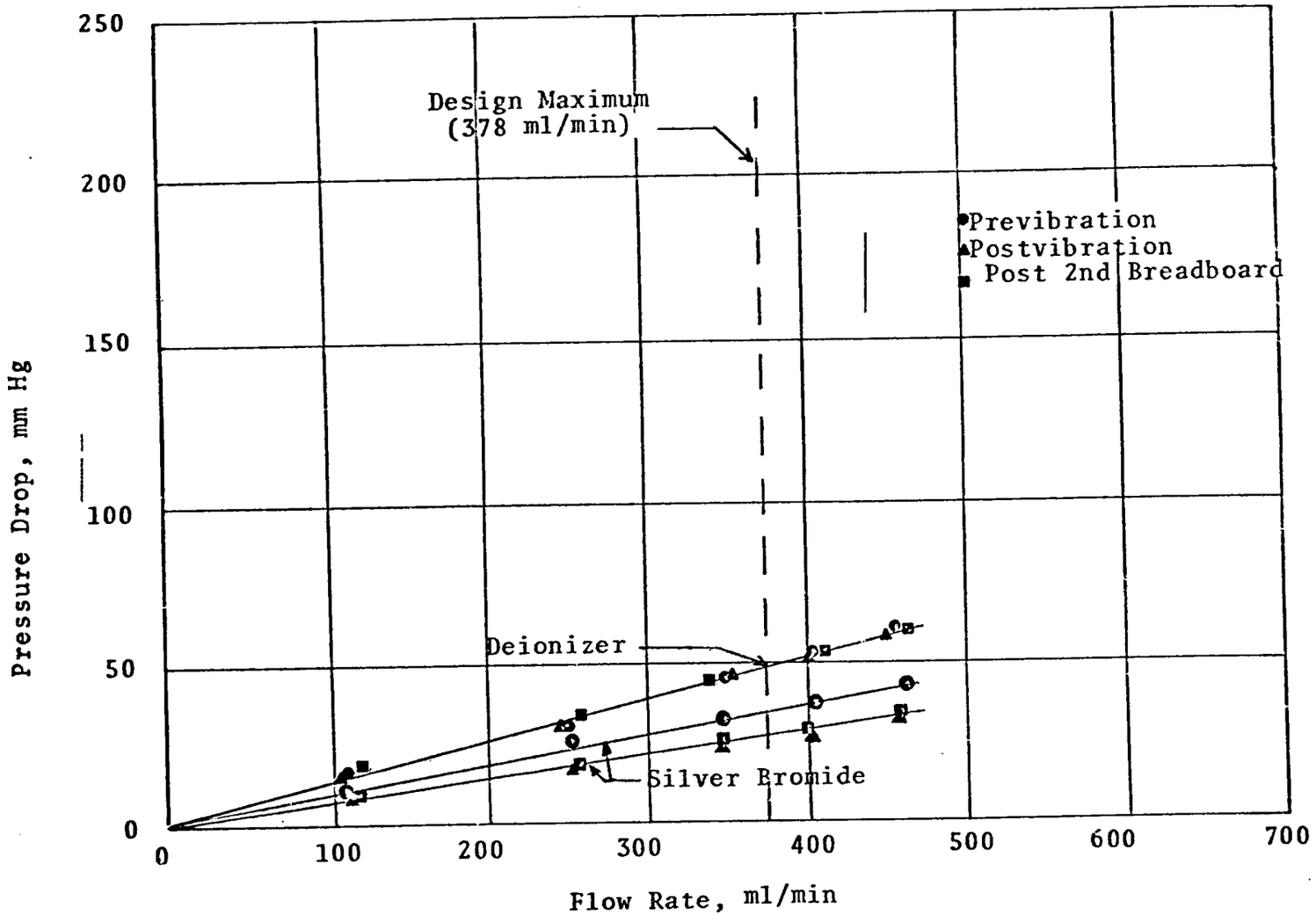

Figure 10 FLOW RESISTANCE OF DEIONIZER AND SILVER BROMIDE COLUMN

The previbration data was collected on the refurbished canisters to establish a baseline for the subsequent tests. Pressure drop measurements taken after vibration show no change from the baseline for the ACF, AgCl and IX columns; however, silver bromide fines were observed being washed-out of the AgBr column. After the measurements were completed, the AgBr column was flushed with deionized water at the product water flow rate of 22.7 liters/hr (50 lb/hr) for 30 minutes. After 30 minutes, influent and effluent turbidity measurements indicated AgBr fines were no longer flushing out.

Following the seven-day performance test, the third set of operating pressure drop characteristics was collected. No changes from the earlier tests were observed in the ACF, AgCl, or IX columns. The flow resistance of the AgBr column remained as in the post-vibration test, slightly decreased in comparison to the baseline. This decrease was probably a result of flow through parts of the column where the fines were washed-out.

Visual inspection of the AgBr canister after the seven-day test and third set of pressure drop measurements indicated the AgBr fines had penetrated the Pyrex wool. The filter was still located in the as-packed original position and had not shifted during vibration. The apparent production of the fines was either a result of packing the canister or of vibrating the canister. More extensive flushing after packing the silver bromide column was indicated for the subsequent PFP testing.

4.4 Breadboard Test No. 2 - Results & Discussion

The second seven-day (168 hour) simulated mission test was performed during the period July 12 to July 18, 1972. The canisters were refurbished with the same composition as used in Breadboard Test No. 1. The objective of the test was to demonstrate that the potable water bactericide system suffered no degradation due to the random vibration testing.

Table 5 lists the daily water quality characteristics of the second breadboard test when processing "worst case" fuel cell water simulant. The tabulated characteristics indicate that the seven-day performance of the canisters after being subjected to simulated launch vibration was satisfactory. The product water was of excellent quality, similar to that produced in the baseline (first) breadboard test. The pH range was 6.9 to 7.1, the specific resistance was always greater than 500,000 ohm-cm and, as in the baseline test, at least 97% of the organics were removed.

Table 5 BREADBOARD TEST No.2 WATER QUALITY CHARACTERISTICS

Test Day & Sample	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)	Count
Day No.1										
Simulant	6.6	22.5	14.5	140	8.1	3.0	7.0	14.3	<0.01	- - -
Stored 4th*	7.0	270.0	0.06	10	<1.0	<1.0	<1.0	4.9	0.90	- - -
Stored 21st*	7.1	275.0	0.06	<5	<1.0	<1.0	<1.0	1.5	0.84	Sterile
Deionizer	7.1	1020.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	830.0	0.02	<5	<1.0	<1.0	<1.0	0.5	0.084	Sterile
Day No.2										
Simulant	6.6	22.0	1..0	140	8.1	2.0	6.0	10.8	<0.01	- - -
Stored 4th*	6.9	390.0	0.04	10	<1.0	<1.0	<1.0	1.0	1.08	- - -
Stored 21st*	7.1	390.0	0.04	10	<1.0	<1.0	<1.0	0.9	0.90	Sterile
Deionizer	7.1	1060.0	- -	<5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	840.0	0.03	<5	<1.0	<1.0	<1.0	1.0	0.086	Sterile
Day No.3										
Simulant	6.5	22.0	15.5	140	8.1	1.4	8.0	12.5	<0.01	- - -
Stored 4th*	6.9	385.0	0.03	20	<1.0	<1.0	<1.0	1.3	1.10	- - -
Stored 21st*	7.0	400.0	0.03	10	<1.0	<1.0	<1.0	1.2	1.16	Sterile
Deionizer	7.1	1060.0	- -	5	- -	- -	- -	- -	<0.01	- - -
Product	7.1	840.0	0.02	5	<1.0	<1.0	<1.0	0.8	0.090	Sterile
Day No.4										
Simulant	6.6	22.5	16.0	140	8.1	1.4	7.0	17.7	<0.01	- - -
Stored 4th*	6.9	390.0	0.05	20	<1.0	<1.0	<1.0	1.5	1.08	- - -
Stored 21st*	6.9	400.0	0.04	10	<1.0	<1.0	<1.0	1.0	1.04	Sterile
Deionizer	7.0	1100.0	- -	5	- -	- -	- -	- -	<0.01	- - -
Product	7.0	860.0	0.03	5	<1.0	<1.0	<1.0	0.6	0.082	Sterile

Dashed indicate no analyses performed
* Denotes Hours

Table 5 Concluded

Test Day & Sample	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)	Count
Day No.5										
Simulant	6.5	22.0	15.0	140	8.1	1.4	7.0	13.4	<0.01	- - -
Stored 4th*	6.8	370.0	0.06	20	<1.0	<1.0	<1.0	1.4	1.04	- - -
Stored 21st*	6.8	380.0	0.06	10	<1.0	<1.0	<1.0	1.3	1.08	Sterile
Deionizer	7.0	950.0	- -	5	- -	- -	- -	- -	<0.01	- - -
Product	7.0	780.0	0.04	5	<1.0	<1.0	<1.0	0.6	0.090	Sterile
Day No.6										
Simulant	6.6	22.0	14.5	140	8.1	1.4	8.0	18.9	<0.01	- - -
Stored 4th*	6.8	340.0	0.05	20	<1.0	1.0	<1.0	1.6	1.04	- - -
Stored 21st*	6.9	350.0	0.06	10	<1.0	1.0	<1.0	1.8	1.06	Sterile
Deionizer	7.0	930.0	- -	5	- -	- -	- -	- -	<0.01	- - -
Product	7.0	720.0	0.03	5	<1.0	<1.0	<1.0	0.4	0.08	Sterile
Day No.7										
Simulant	6.5	22.5	16.5	140	8.1	1.0	10.0	14.9	<0.01	- - -
Stored 4th*	6.6	300.0	0.06	20	<1.0	1.0	<1.0	1.4	1.04	- - -
Stored 21st*	6.6	310.0	0.04	10	1.0	1.0	<1.0	1.4	1.02	Sterile
Deionizer	6.9	710.0	- -	5	- -	- -	- -	- -	<0.01	- - -
Product	6.9	520.0	0.02	5	<1.0	<1.0	<1.0	0.5	0.08	Sterile

Dashes indicate no analyses
* Denotes Hour

As in the first breadboard test, the silver bromide column dosed the deionizer effluent with silver ions ranging in concentration between 0.08 and 0.10 ppm. The Breadboard Potable Water Bactericide System exhibited no chemical degradation due to the random vibration testing.

Daily sterility determinations were performed on stored water and product water by innoculating thioglycolate broth; the tubes were incubated at 308°K (95°F) and inspected at 24 and 48 hours for turbidity. The stored water and the first 500 ml of product water drawn-off at the outlets after 21 hours of dormancy (no draw-off in the interim) were determined to be sterile.

4.5 Conclusions

The two breadboard tests conclusively showed that the Breadboard Potable Water Bactericide System is capable of producing potable water for at least seven days. The system (1) exhibited no degradation due to vibration testing, (2) maintained sterility throughout the system during the seven operating days, and (3) demonstrated that the former chemical problems had been satisfactorily resolved, except for silver ion dose in the product water.

The silver ion dose was in accord with published literature values* on the solubility of silver bromide - i.e., 0.08 to 0.1 ppm at ambient temperatures. It is concluded that a fraction of the deionizer effluent must bypass the AgBr Column to obtain a silver ion dose $\leq$ 0.05 ppm in the product water.

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* Solubilities, Vol 1. 4th Ed., American Chemical Society, Washington, D. C. (1958).

PRELIMINARY FLIGHT PROTOTYPE DESIGN

A preliminary flight prototype water bactericide system was to be designed, fabricated and tested under Contract NAS 9-12792. The design was to be based upon (1) the results of Contract NAS 9-12104, (2) the results of the breadboard system shock and vibration tests and (3) the results of the breadboard system performance tests.

Four breadboard canister housings (the activated charcoal filter, the silver chloride column, the deionizer, and the silver bromide column) developed under Contract NAS 9-12104* were utilized "as is" in the Preliminary Flight Prorotype design. The system, except for the biological filter, is an assembly of upgraded and tested breadboard canisters. The components that define the treating system in the order of their use are as follows: (1) biological filter,(2) activated charcoal and ion exchange resin canister,(3) silver chloride canister,(4) deionizer, and (5) silver bromide canister.

5.1 Design Considerations

The design practices employed were cognizant of reliability, quality assurance,and safety.

5.1.1 Reliability

Although a reliability study was not performed, related CHEMTRIC efforts on the development of the water and waste management system for a modular Space Station** provided direction in the design effort. The failure modes of the canisters are (1) external leakage, (2) channeling, and (3) clogging. The probability for external leakage is reduced through the use of welded connections and a single removable seal of the "O" ring variety. Corrosion induced leakage is minimized through material selection, elimination of crevices, heat treatment and passivation. The media compression spring retards bed shifting which can promote channeling; the media restraint also reduces the probability of particle disintegration which if unchecked could lead to off-quality water and clogging of the outlet media retainer.

The combination of perforated metal discs, screens and Pyrex wool as media retainers provides a "depth" type filtration capability; this arrangement is less prone to clogging than a "membrane filter" type retainer. In the case of the biological filter,a bypass relief valve provides an alternate hydraulic path for the fuel cell water should the "membrane filter" clog.

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* Hurley, T. L. and Bambenek, R. A. , ibid

** Subcontract SS-863762-KO with the Hamilton Standard Division of the United Aircraft Company, under Contract NAS 9-10273.

5.1.2 Quality Assurance

The performance of the PFP potable water bactericide system is related to chemophysical processes and the materials composing the various contacting beds affect the quality of the product water. Preparation, packing, and sterilization of these materials was conducted in accordance to developed procedures (CHEMTRIC Assembly Procedures 3100).

The cartridge design concept for the silver halide columns (AgCl and AgBr) minimizes the breakthrough of silver halide fines during launch environments. The silver halide fines produced during the packing are readily washed-out in the preparation procedures.

The design emphasizes control of corrosion. The canisters, brackets and tubing were fabricated from 316 stainless steel. Welding was employed to join components; butt welding was used in lieu of lap-type unions. The assembly was heat treated and annealed to minimize the potential for intergranular corrosion, and then passivated. Subsequent cleaning and decontamination procedures were performed, without the use of abrasives, to preserve the integrity of the passivated surfaces.

5.1.3 Safety

A safety hazards analysis was not conducted but safety goals were considered in the design. In regard to the canisters, the only mechanical safety hazard identifiable at this time is the spring loaded end cap. Once the "V" band clamp is removed, the media compression spring can propel the end cap outward. However, sterility requirements dictate no inflight maintenance, especially at the component repair level. The design of the flight system should provide positive means to prevent canister disassembly.

The performance of the system will be monitored by pH, silver ion concentration and pressure differential. The pH sensor will determine the hydrogen ion concentration and indirectly indicate absorption capacity breakthrough. The silver ion sensor will determine the silver ion concentration, and the quantity will indicate potability and its relative bactericidal/bacteriostatic effectiveness or toxicity. The delta pressure sensor will determine any changes in flow resistance - i.e., clogging or channeling.

A check valve was incorporated into the biological filter to prevent back flow of AgCl dosed water to the fuel cell and to protect the filter cartridge from excessive back pressures.

5.2 Biological Filter

Pall Trinity Micro Corporation's housing P/N MCS 1001G16 and filter cartridge P/N MCY1001UR were used in the Breadboard Tests (Section 4) and under Contract NAS 9-12104. The housing and cartridge had adequate "dirt capacity" as evidenced by the test results. The design, however, would not withstand the shock and vibration during launch because the cartridge is supported within the housing in a cantilevered fashion.

Figure 11 illustrates the biological filter that was developed under this program. This component contains a filter cartridge, a check valve, a bypass relief valve, and a AgCl column. The filter cartridge is Pall Trinity Micro Corporation's Part No. AB1AR8A. The cartridge is 25.4 cm (10.0 inches) long and has an outside diameter (OD) of 7.02 cm (2.76 inches). It has a pleated membrane-type filter area of 0.4645 square meters (5.0 square feet). The filtering element is rated for absolute retention of all particles 0.20 microns and larger. The fabricated filter media is two sheets of material made of a proprietary blend of inert inorganic fibers and an inert organic binder with supporting and protecting cellulose sheets, melt-sealed to polypropylene end caps which are in turn melt-sealed to a perforated polypropylene protective sleeve.

The filter cartridge is spring loaded for stability during vibration. The selected spring provides 2.33 Newtons of force per centimeter (1.33 pounds per inch) of length, from 17.4 cm (6.85 inches) (free length) to 6.27 mm (0.247 inch) (solid length). The target compressive load, 35.6 Newtons (8 lb) is applied when the spring is compressed to 2.16 cm (0.85 inch). The spring is fabricated from 2.159 mm (0.085 inch) type 18-8 stainless steel wire. Other characteristics of this spring are as follows:

Mean Coil Diameter	= 6.45 cm (2.54 in)
Number of Active Coils	= 3-1/2
Total Number of Coils	= 5-1/2

The check valve is incorporated into the design between the AgCl column and the filter cartridge; the cracking pressure of the check valve is 0 to 13,800 Newtons per square meter differential (0 to 2 psid). The check valve prevents backflow of AgCl dosed water towards the fuel cell and protects the filter cartridge from excessive back pressures.

The bypass relief valve incorporated into the design in case of filter cartridge blockage has a cracking pressure of 103,000 Newtons per square meter differential (15 psid). Silver dosing of the water is accomplished in either normal or the bypass configuration. As in the other columns, the AgCl contents

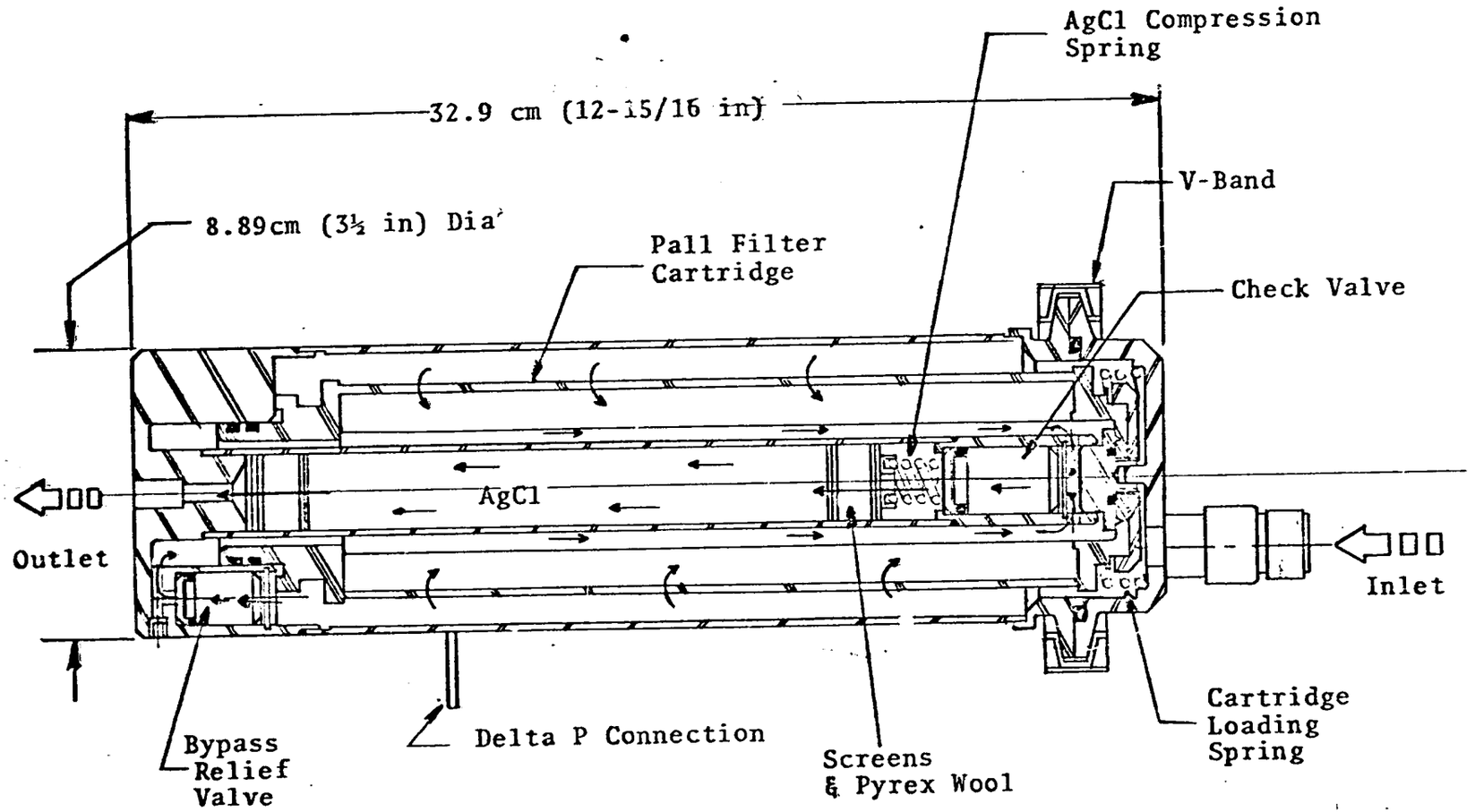


Figure 11 BIOLOGICAL FILTER

in the biological filter are spring loaded. The selected spring provides 16.1 Newtons of force per centimeter of length (9.2 lbs of force per inch of length) from 3.07 cm (1.21 inches) (free length) to 4.32 mm (0.17 inches); the target compressive load, 26.7 Newtons (6 lbs) is applied when the spring is compressed to 1.42 cm (0.56 inches). The spring is fabricated from 1.22 mm (0.048 inch) type 18-8 stainless steel wire. Other characteristics of this spring are as follows:

Mean Coil Diameter	= 1.45 cm (0.57 in)
Number of Active Coils	= 3-1/2
Total Number of Coils	= 5-1/2

5.3 Activated Charcoal and Ion Exchange Resin Canister

Figure 12 illustrates the design of the activated charcoal and ion exchange resin canister. This canister contains beds of activated charcoal and ion exchange resins. The activated charcoals are used to adsorb the organic contaminants. The ion exchange resins are used to absorb the chlorides, and subsequently minimize the "common ion effect" and thereby increase the solubility of AgCl. The activated charcoal bed is composed of a mixture of 1063 cm^3 (64.8 in^3) of Westvaco's Nuchar WV-G and 708 cm^3 (43.2 in^3) of Union Carbide's Columbia LCJ. The ion exchange bed is composed of a mixture of 482 cm^3 (29.3 in^3) Amberlite IR-120, 359 cm^3 (21.9 in^3) of Amberlite IRA-402, and 239 cm^3 (14.6 in^3) of Amberlite IR-45.

5.4 Silver Chloride Canister

Figure 13 illustrates the design of the silver chloride canister. The cartridge concept was developed to facilitate preparation and washing of the AgCl bed. As indicated by Figure 13 all of the influent passes through the cartridge. The cartridge contains 312 grams (dry) of the AgCl-glass bead mixture. The diameter of the AgCl contents is 3.49 cm (1.374 inches) and the effective length is 13.97 cm (5.50 inches).

5.5 Deionizer

Figure 14 illustrates the design of the deionizer. Mechanically, this component remains the same as developed under contract NAS 9-12104. The contents of the deionizer were upgraded and established during the Preliminary Testing (Section 2) and during the Breadboard Tests (Section 4). The deionizer contains a mixed bed of ion exchange resins composed of 200 cm^3 (12.1 in^3) of Amberlite IR-120, 150 cm^3 (9.1 in^3) of Amberlite IRA-402, and 100 cm^3 (6.1 in^3) of Amberlite IR-45. The effective diameter of the bed is 4.2 cm (1.652 inches) and the effective length is 32.5 cm (12.8 inches).

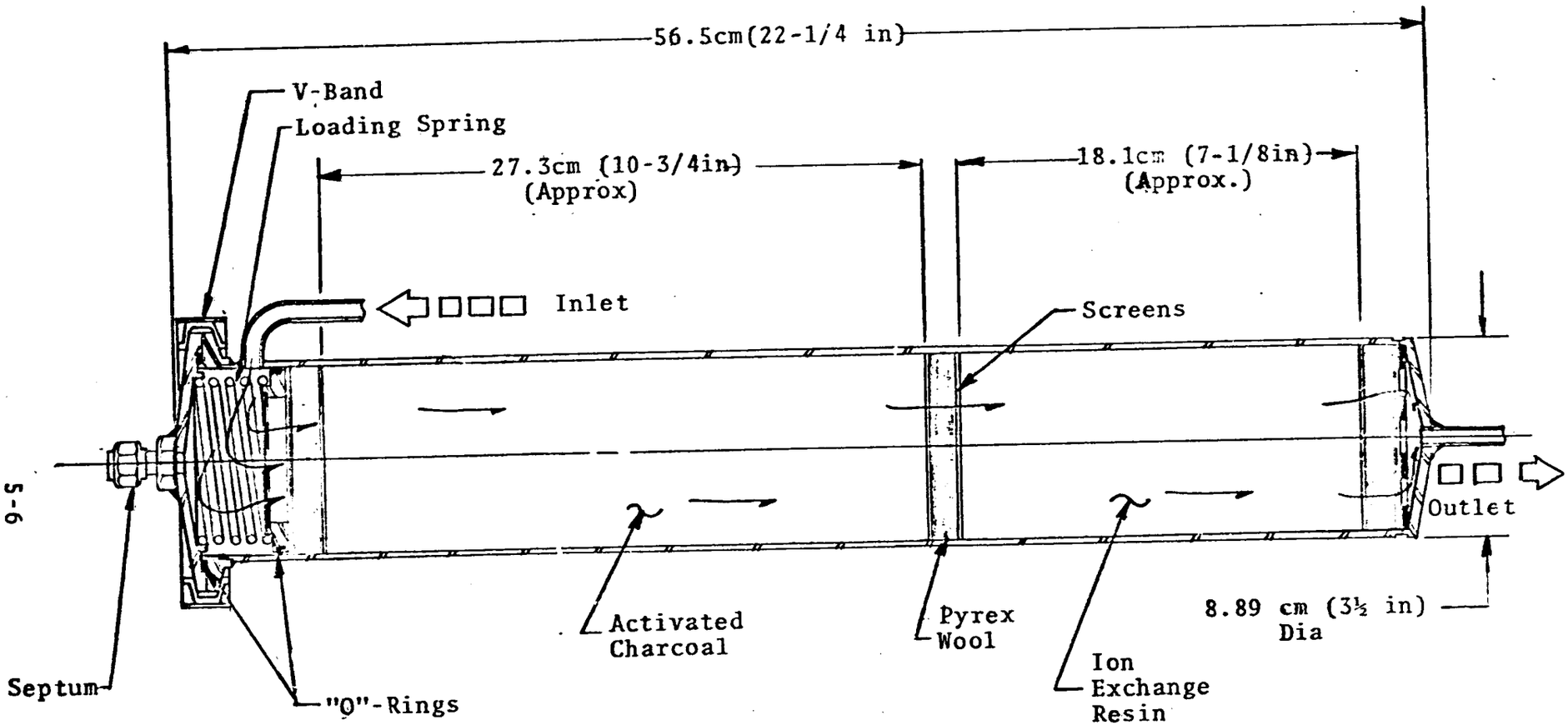


Figure 12 ACTIVATED CHARCOAL & ION EXCHANGE RESIN CANISTER

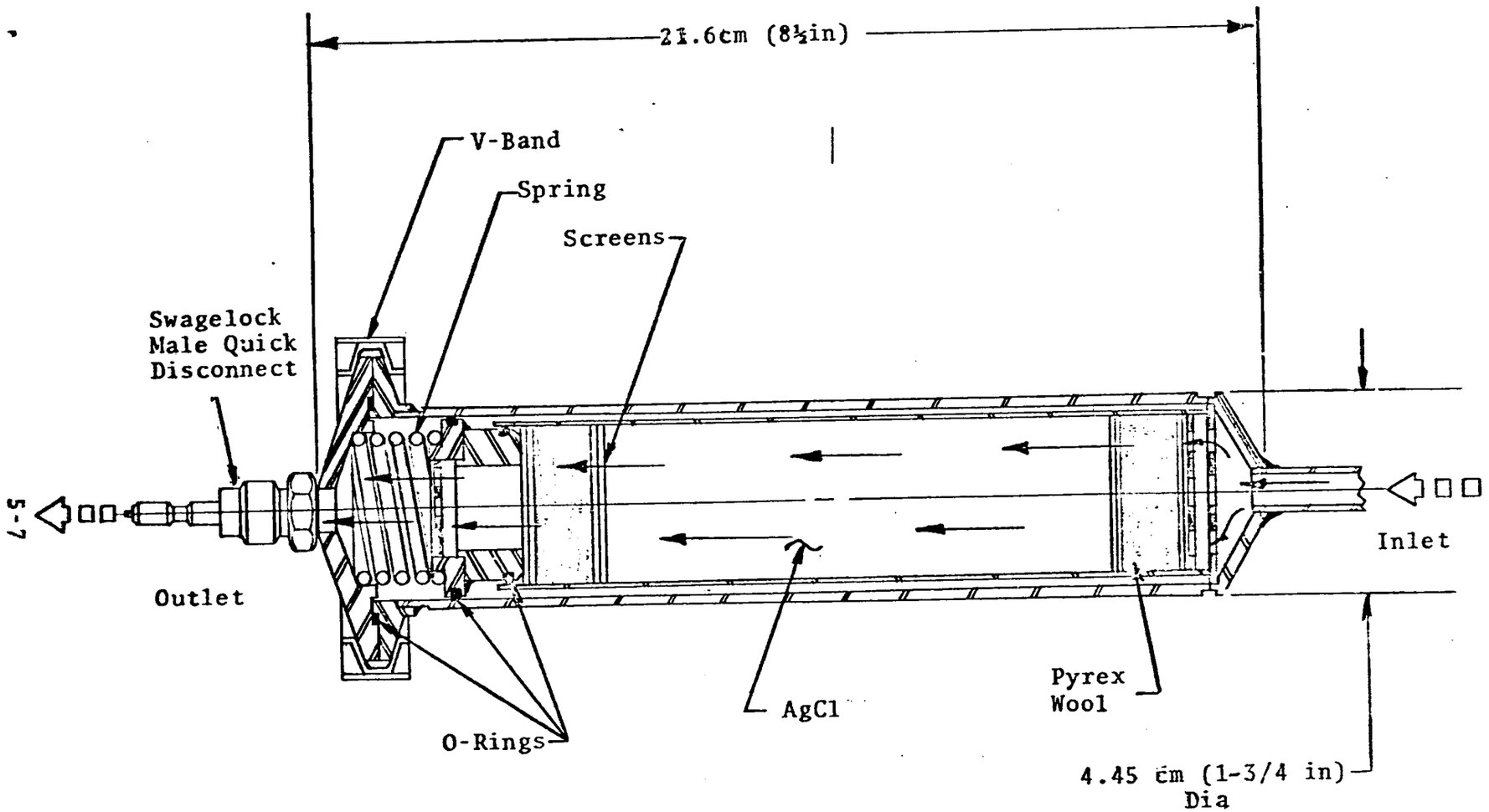


Figure 13 SILVER CHLORIDE CANISTER

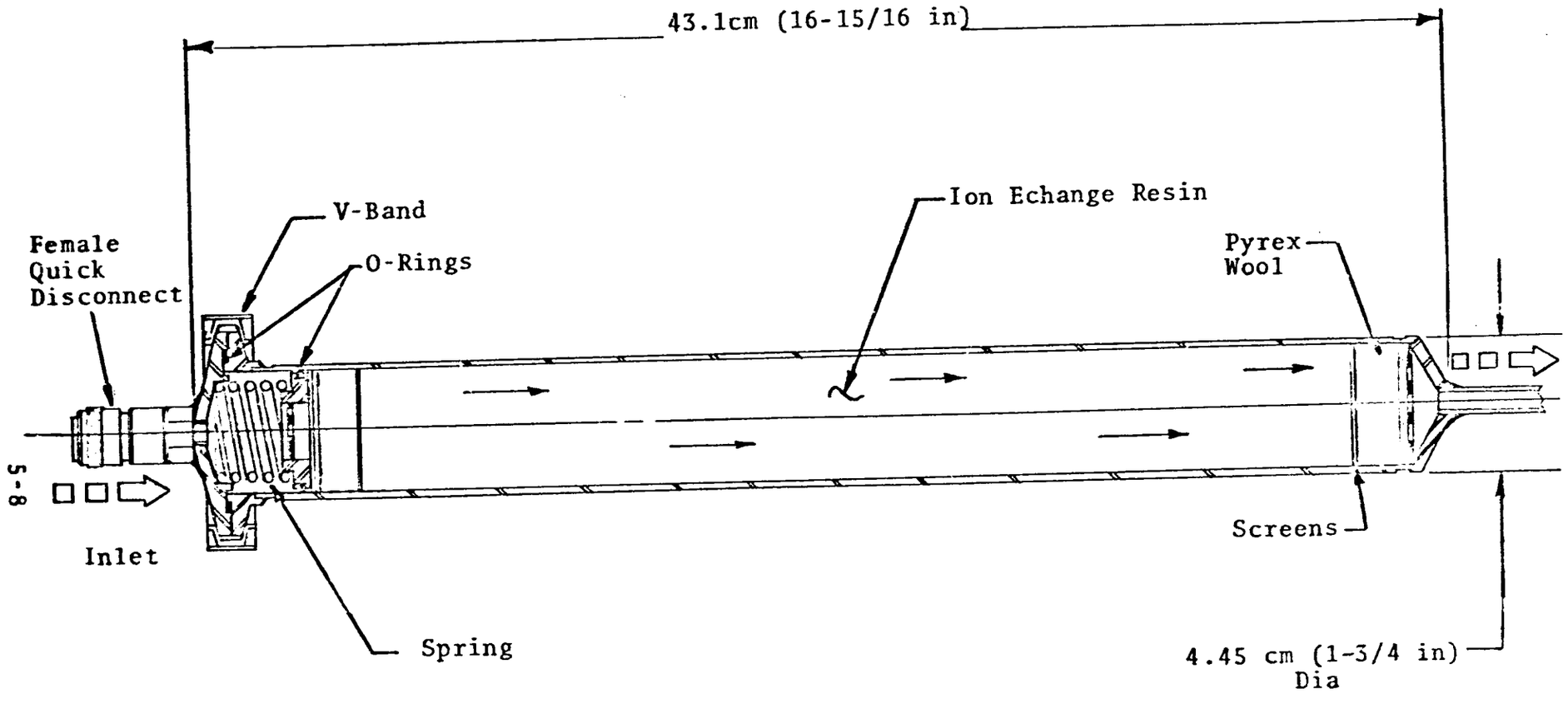


Figure 14 DEIONIZER

5.6 Silver Bromide Canister

Figure 15 illustrates the design of the silver bromide canister. This component was upgraded by the inclusion of a bypass cartridge. The cartridge concept was developed to (1) facilitate preparation and washing of the AgBr and (2) bypass some water passing through the canister to obtain a silver dose of approximately 0.050 ppm in the product water. As indicated by Figure 15, the cartridge design allows up to 50% bypass of deionizer effluent flow. To achieve this bypass, the AgBr contents in the canister was decreased to approximately 45% of that employed in the Breadboard Testing and under Contract NAS 9-12104. The AgBr cartridge contains 148 grams (dry) of AgBr-glass bead mixture. The diameter of the AgBr contents is 2.75 cm (1.084 inches) and the effective length is 13.8 cm (5.44 inches).

5.7 The Preliminary Flight Prototype Assembly

Figure 16 shows the Preliminary Flight Prototype that was developed under this program. As shown in the photograph, the system is an assembly of canisters. The prototype system includes mock-ups representing three instruments: (1) a pH meter and its signal conditioning circuitry, (2) a silver ion meter and its signal conditioner, and (3) a system delta-pressure transducer and its signal conditioner. The characteristics of Beckman's Apollo pH meter (i.e., size, weight and center of gravity) were utilized for the mock-ups representing both the pH and silver ion meter and their signal conditioners. Similarily, the characteristics of the Statham delta-pressure transducer were employed for the system delta-pressure transducer mock-up.

The Preliminary Flight Prototype utilizes the stressed-member principle for the system packaging concept. Four sheet metal channels join all canisters and components near, but not on their nodal points. Each canister supports its own vibration stresses as well as its own pressure loading, but its loading from other components is minimal.

All metal-to-metal joining was accomplished by heli-arc welding. After welding, the entire assembly was heat treated to a fully stress-relieved condition to maximize corrosion resistance. After heat treatment the assembly was passivated.

5.8 Interface Requirements

The interface requirements for the Preliminary Flight Prototype are as follows:

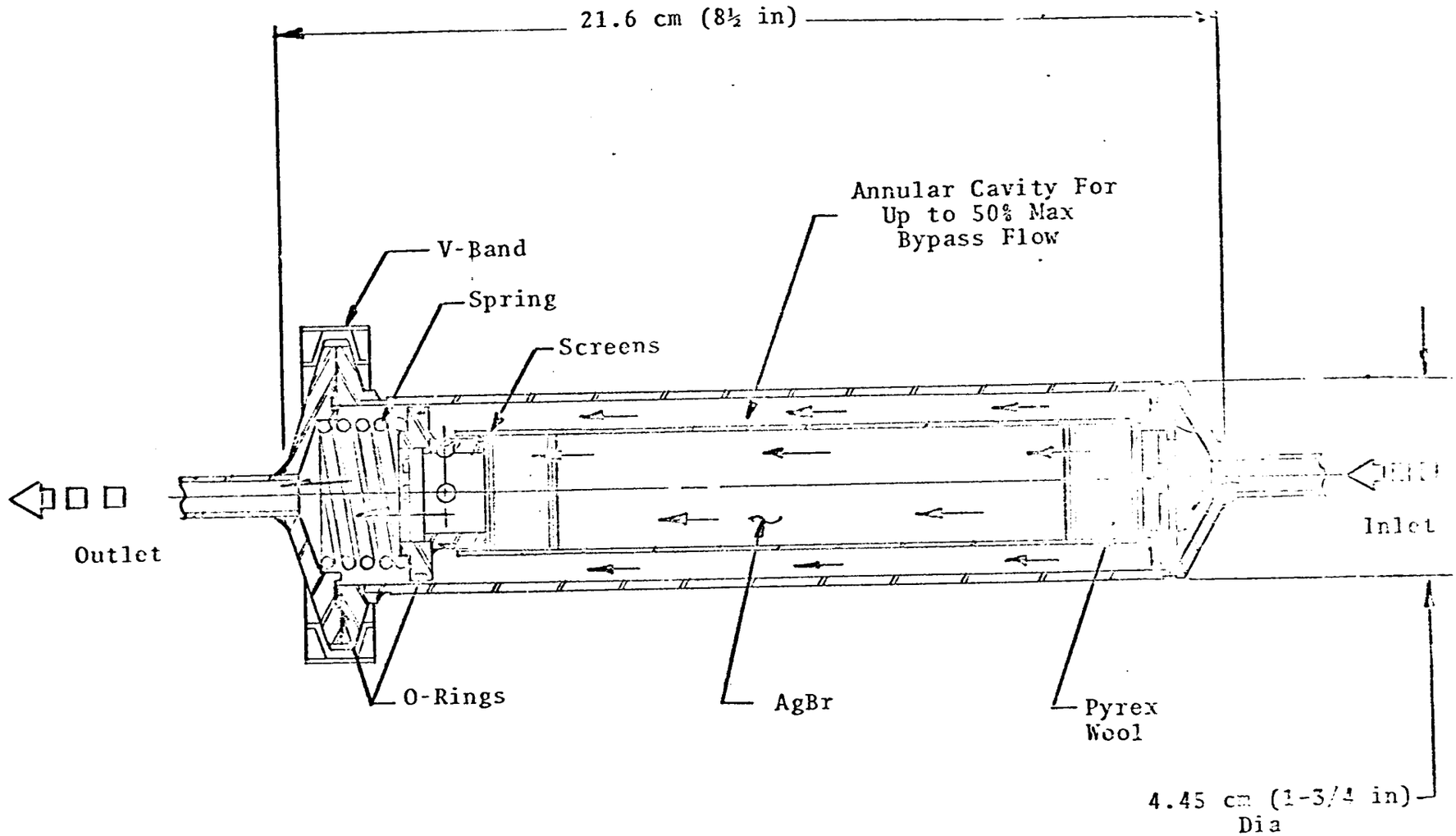
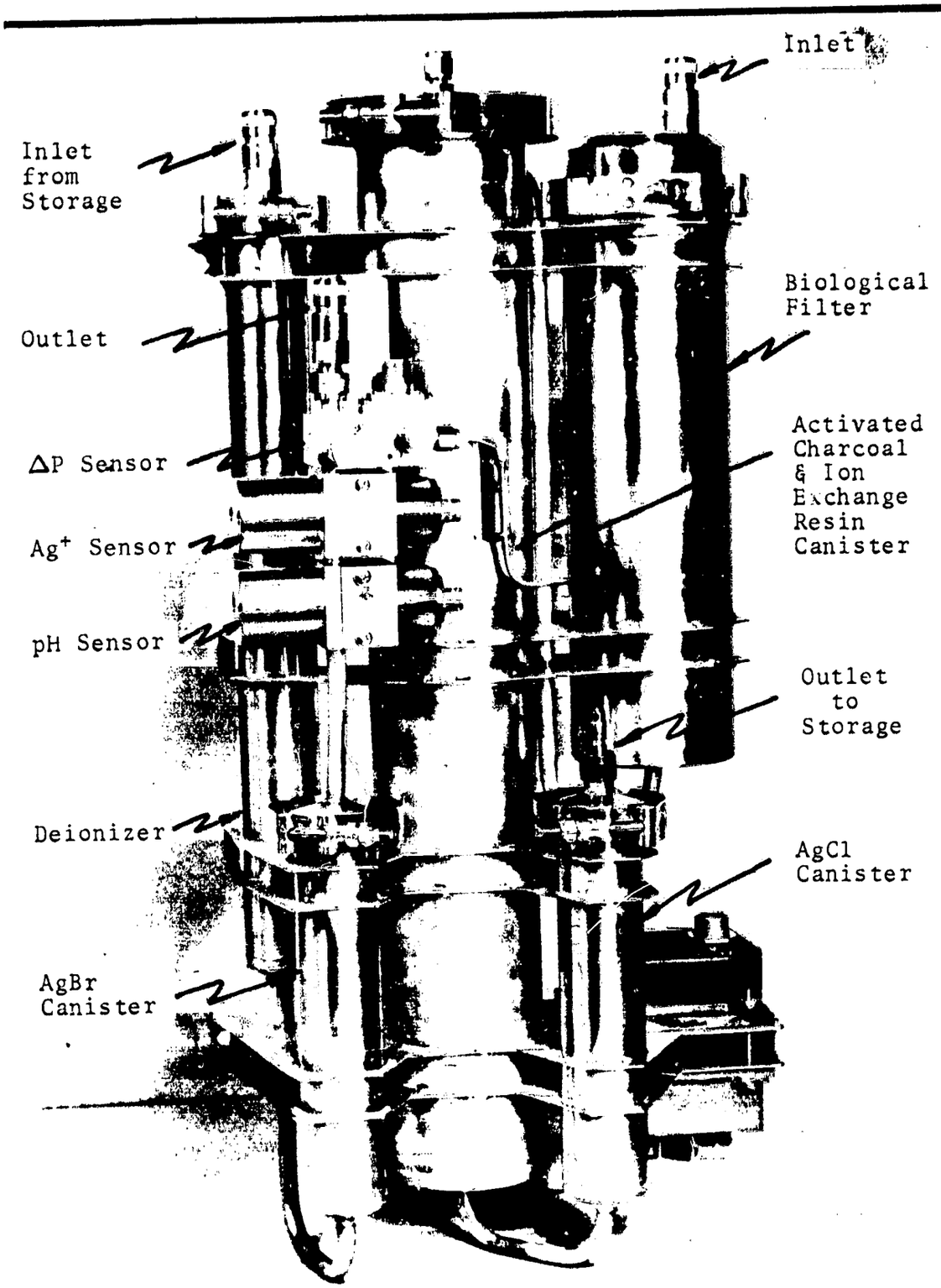


Figure 15 SILVER BROMIDE CANISTER



Figur 16 PHOTOGRAPH OF THE PRELIMINARY FLIGHT PROTOTYPE

A. Mechanical
   1. Weight (packed and wet) - 20.9 kg (46 lb)
   2. Dimensions - 61.3 cm (24-1/8 in) x 28.9 cm (11-3/8 in) x 17.8 cm (7 in)
   3. Four Fasteners - To Be Determined

B. Electrical
   1. Delta Pressure Transducer - To Be Determined
   2. pH Sensor - To Be Determined
   3. Ag^+ Sensor - To Be Determined

C. Thermal
   1. Minimum Temperature 277°K (40°F)
   2. Maximum Temperature 303°K (86°F)

D. Hydraulic
   1. Four flexible metal hose connectors (Swagelock P/N 600-6FH (3/8 S) - 316 SS)
   2. Four Quick-Connects with double end shut-off (Swagelock P/N 600-QC-6 DESO - 316 SS)

The Preliminary Flight Prototype unit is to be installed into the potable water system downstream of the fuel cells. The inlet portion of the PFP (i.e., the biological filter, the activated charcoal and ion exhange resin canister, and the silver chloride canister) is to be installed upstream of the potable water storage tanks; whereas, the outlet portion of the PFP (i.e., the deionizer and the silver bromide canister) is to be installed downstream of the potable water storage tanks and just upstream of the heater and chiller at the draw off station.

A heat exchanger may be required to cool the fuel cell water. The influent fuel cell water should be at a temperature, 294 - 297°K (70 - 75°F). If the influent fuel cell water is at the fuel cells exit temperature, 339 - 353°K (150 - 175°F) the product water will be dosed with 0.34 to 0.68 ppm of silver ion and not be within the silver ion concentration required for potability (0.05 ppm maximum).

Maintenance of a flight system is required on two levels: (1) on the ground, to permit refurbishment of the system for the next flight and (2) in the vehicle, to provide reliable and safe hydraulic and mechanical connections. Flexible metal hoses and Quick-Connects with double end shut off were selected to make the connections and to minimize turn-around time. Utilization of Quick-Connects also permits in-flight maintance to increase reliability or to extend mission capability with spare units.

PRELIMINARY FLIGHT PROTOTYPE TESTS

6.1 PFP Test No. 1

A seven-day simulated mission test was performed with the Preliminary Flight Prototype System during the period November 27 to December 3, 1972. The objective of the test was to establish a performance baseline.

6.1.1 PFP Column Preparations

After passivation the PFP assembly was washed, rinsed, and prepared in accordance with procedures previously developed and used in the two breadboard tests. The newly designed biological filter canister contains Pall Trinity Micro Corporation's Ultipor AB Filter Cartridge, Model AB1AR8A which has filter media with a 0.20 micron absolute particle retention, plus 146 grams (dry) of AgCl-glass bead mixture.

The activated charcoal canister was packed with a mixed bed of activated charcoals (1063 cm^3 of Westvaco's Nuchar WV-G and 708 cm^3 of Union Carbide's Columbia LCJ) plus a mixed bed of ion exchange resins (482 cm^3 of Amberlite IR-120, 359 cm^3 of Amberlite IRA-402, and 239 cm^3 of Amberlite IR-45). The newly designed cartridge for the AgCl canister was packed with 312 grams (dry) of AgCl-glass bead mixture. The deionizer was packed with a mixed bed of ion exchange resins (200 cm^3 of Amberlite IR-120, 150 cm^3 of Amberlite IRA-402, and 100 cm^3 of Amberlite IR-45). The newly designed by-pass cartridge for the AgBr canister was packed with 148 grams (dry) of AgBr-glass bead mixture.

The packed PFP assembly was sterilized at 344 - 347°K (160 - 165°F) for 24 hours with 35 ml/min deionized water flushing. The sterilization cycle was performed in a deionized water bath.

6.1.2 Test Set-Up and Procedure

Figure 17 shows the arrangement of components used in the PFP test. The components that define the water treating system in the order of their use are as follows: (1) biological filter, (2) activated charcoal filter, (3) silver chloride column, (4) deionizer, and (5) silver bromide column.

The PFP system processed "worst case" fuel cell water at ambient temperatures, 294 - 297°K (70 - 75°F). *Pseudomonas aeruginosa* and Type IIIa bacteria were injected through the septums at the water heater and chiller outlets. Half of the draw-off water passed through the heater maintaining the water at 330 - 336°K (135 - 145°F) and the other half of the draw-off water passed through the chiller maintaining the water at 279 - 282°K (42 - 48°F). One milliliter suspensions containing 10^2, 10^3, or 10^4 bacteria/ml were injected at both hot and cold water outlet valves.

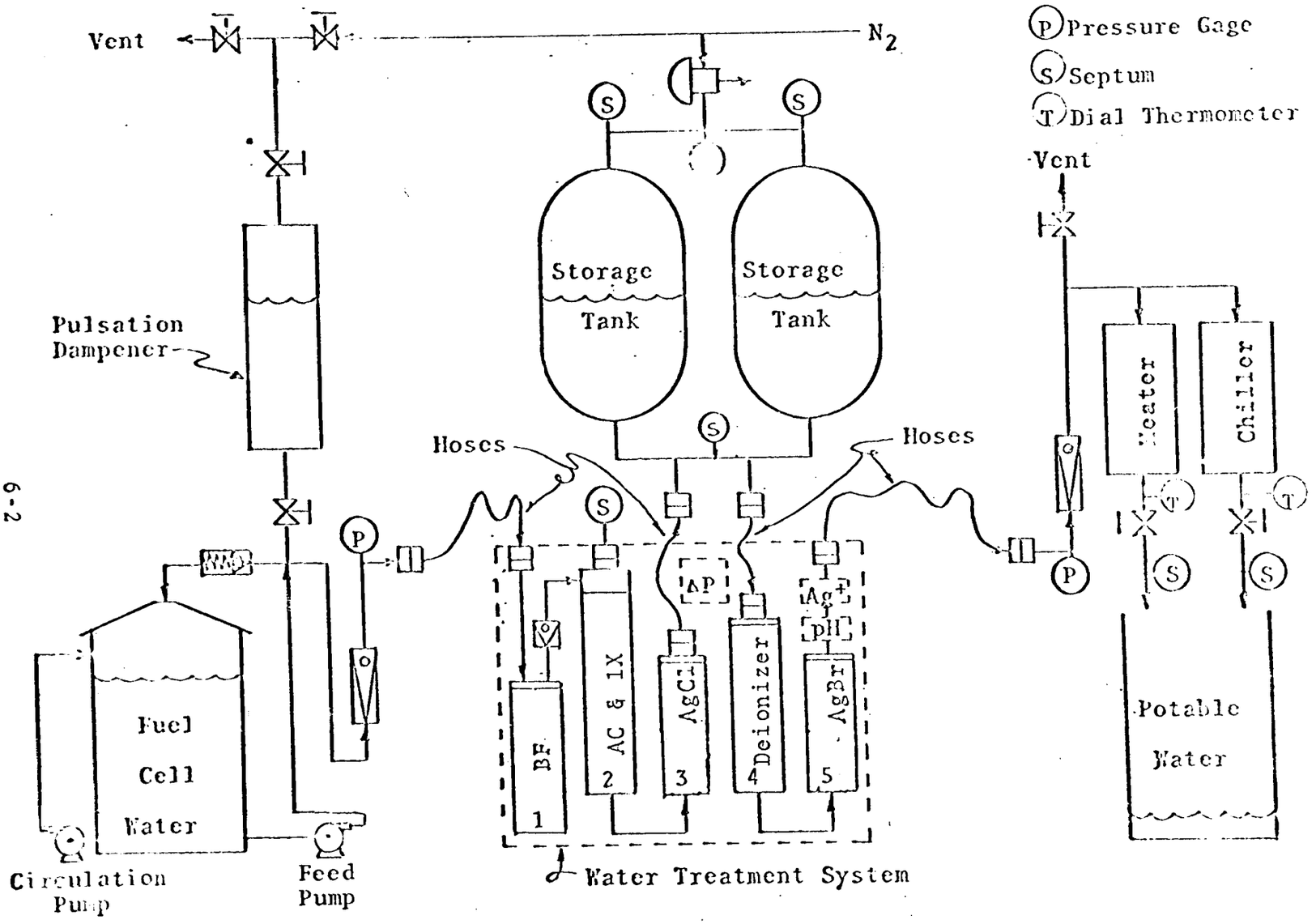


Figure 17 FLOW SCHEMATIC FOR PFP SIMULATED MISSION TESTS

6.1.3 Test Results & Discussion

Table 6 lists the daily water quality characteristics of the PFP when processing "worst case" fuel cell water simulant. The tabulated "key" characteristics indicate that the system performed satisfactorily and according to predictions. The water quality was excellent and within all specifications. The silver ion dose was below 0.05 ppm (0.018-0.03 ppm Ag^+) and the bypass was operating. The silver ion concentration was lower than originally calibrated (ca 0.047 ppm Ag^+); it appears that one of the O-ring plugs moved during subsequent handling and had changed the bypass flow.

Table 7 lists the daily doses of bacteria injected and plate counts on samples of hot and cold water at the outlet valves. The tabulated data show that 0.018-0.03 ppm Ag^+ dose provided bactericidal activity against the infusion of 10^4 Pseudomonas aeruginosa and/or Type IIIa at both the hot and cold water outlets.

6.2 Vibration Testing

The PFP unit, packed and sterilized, was secured to a vibration test fixture. The assembly was then subjected to the random vibration, specified in Section 1.2, at the Inland Testing Laboratories, Inc., Morton Grove, Illinois; see the Appendix C ITL Test Report No. 3412-2.

6.2.1 External Examination and Test

A cursory visual examination at Inland Testing Laboratories revealed no evidence of physical damage after vibration. Detailed inspection and tests by CHEMTRIC after vibration, however, revealed that the 3.18 mm (1/8 inch) OD tubing used to connect the mocked-up delta P transducer had cracked. Since this was on a mock-up and did not affect the sterility of the system, the crack was silver soldered and the SMT initiated. No other evidence of physical damage was apparent.

6.2.2 Flow Resistance of Packed PFP Assembly - Hydraulic Testing

The operating pressure drop characteristics of the PFP units inlet and outlet sides were determined three times; namely, previbration, postvibration, and post SMT. Figures 18 and 19 present the results of the three tests.

The previbration data was collected on the refurbished unit to establish a baseline for subsequent comparisons. Pressure drop measurements after vibration show a decrease in flow resistance on the inlet side of the PFP (see Figure 18). No fines were

Table 6 PFP TEST No.1 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	7.5	22?0	15.0	140	8.1	<1.0	16.0	122	<0.01
	Stored 4th*	7.3	320.0	0.07	20	<1.0	<1.0	<1.0	6	0.96
	Stored 21st*	7.3	390.0	0.05	10	<1.0	<1.0	<1.0	7	1.18
	Product	7.3	810.0	0.03	<5	<1.0	<1.0	1.0	4	0.024
2	Simulant	6.4	23.5	14.5	140	8.1	2.0	6.0	111	<0.01
	Stored 4th*	7.5	285.0	0.04	20	<1.0	1.0	.2.0	8	1.20
	Stored 21st*	7.4	305.0	0.07	10	<1.0	<1.0	<1.0	14	1.20
	Product	7.3	780.0	0.04	<5	<1.0	1.0	1.0	3	0.020
3	Simulant	6.3	24.0	14.5	140	8.1	2.0	6.0	85	<0.01
	Stored 4th*	7.4	290.0	0.10	20	<1.0	1.0	<1.0	6	1.08
	Stored 21st*	7.4	310.0	0.08	10	<1.0	<1.0	<1.0	5	1.16
	Product	7.3	710.0	0.04	<5	<1.0	1.0	<1.0	2	0.024
4	Simulant	6.4	24.0	14.0	140	8.1	2.0	8.0	80	<0.01
	Stored 4th*	7.4	270.0	0.11	20	<1.0	<1.0	<1.0	5	1.20
	Stored 21st*	7.4	300.0	0.14	10	<1.0	<1.0	<1.0	9	1.04
	Product	7.3	680.0	0.05	<5	<1.0	1.0	<1.0	1	0.030
5	Simulant	6.4	24.5	14.5	140	8.1	2.0	4.0	68	<0.01
	Stored 4th*	7.5	210.0	0.08	20	<1.0	1.0	<1.0	3	1.20
	Stored 21st*	7.4	300.0	0.05	10	<1.0	<1.0	<1.0	4	1.16
	Product	7.2	580.0	0.04	<5	<1.0	1.5	<1.0	6	0.026

* Denotes Hour

Table 6 Concluded

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
6	Simulant	6.4	24.5	14.0	140	8.1	2.0	6.0	114	<0.01
	Stored 4th*	7.3	240.0	0.14	20	1.0	1.5	1.0	29	1.22
	Stored 21st*	7.3	310.0	0.10	10	<1.0	<1.0	<1.0	18	1.18
	Product	7.2	530.0	0.07	<5	<1.0	1.5	<1.0	5	0.022
7	Simulant	6.4	25.0	14.5	140	8.1	3.0	4.0	109	<0.01
	Stored 4th*	7.2	210.0	0.11	20	<1.0	1.5	<1.0	11	1.18
	Stored 21st*	7.2	300.0	0.08	10	<1.0	<1.0	<1.0	7	1.14
	Product	7.2	410.0	0.07	5	<1.0	1.5	1.0	4	0.018

* Denotes Hour

Table 7 SUMMARY OF BACTERIOLOGIC ANALYSES FOR PFP TEST No.1

Test Day	Dosages: Hot Water Outlet	Dosages: Cold Water Outlet	Stored Water	Sample Points: Hot O.V.* Hr.	Hot O.V.* Count	Cold O.V. Hr.	Cold O.V. Count
1	10^2 P. aeruginosa	10^2 P. aeruginosa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
2	10^3 P. aeruginosa	10^3 P. aeruginosa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
3	10^4 P. aeruginosa	10^4 P. aeruginosa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
4	0	0	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
5	10^2 Type IIIa	10^2 Type IIIa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
6	10^3 Type IIIa	10^3 Type IIIa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml
7	10^4 Type IIIa	10^4 Type IIIa	Sterile	22 23	<1/200ml <1/200ml	23 24	<1/200ml <1/200ml

* O.V. = Outlet Valve

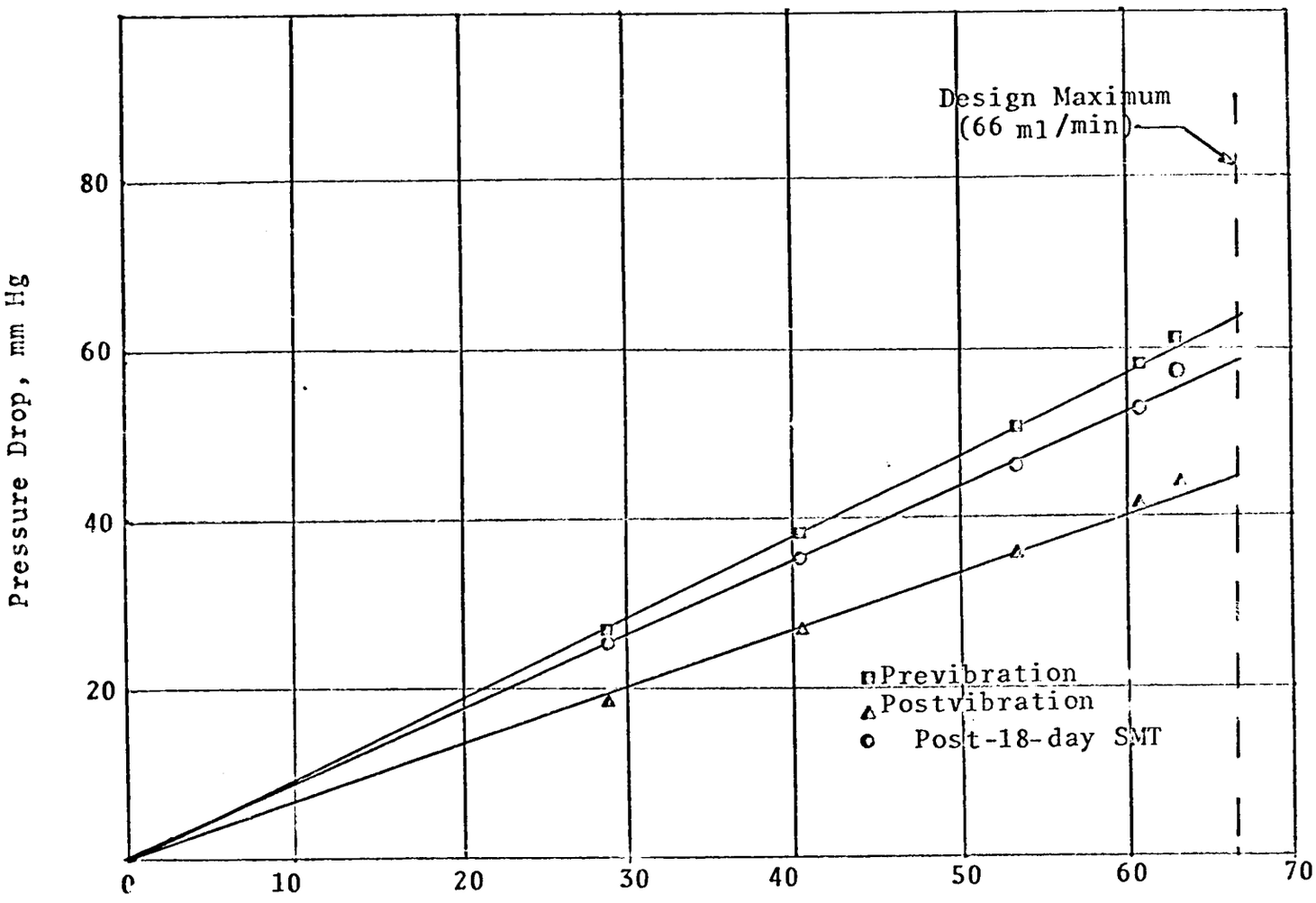


Figure 18 FLOW RESISTANCE ON INLET TO STORAGE SIDE OF PFP

observed in the effluent during the postvibration hydraulic tests. It is surmised that the random vibrations dislodged AgCl fines within the AgCl column in the biological filter canister and this decreased the flow resistance. It appears that these fines were filtered-out in the Pyrex wools or the beds of activated charcoals and ion exchange resins within the activated charcoal/ion exchange resin canister, but their presence in this canister did not significantly affect pressure drop because the cross sectional area for flow is twelve (12) times larger in the activated charcoal/ion exchange canister than in the AgCl column within the biological filter canister.

Following the 18-day SMT, the third set of operating pressure drop data was collected. Figure 18 shows an increase in flow resistance on the inlet side of the PFP. The increase was expected and was a result of the accumulation of particulates on the biological filter during the 18-day test period.

Pressure drop measurements on the outlet side of the PFP, Figure 19, show no significant changes in hydraulic characteristics after vibration and after 18 test days.

6.3 PFP Test No. 2

An eighteen-day simulated mission test was performed with the Preliminary Flight Prototype System during the period December 11, 1972 to January 5, 1973. The objectives of the test were to determine useful life of the system and to demonstrate that the system suffered no biochemical degradation due to random vibration testing.

6.3.1 Refurbishment of the PFP

After completion of PFP Test No. 1, the PFP canisters were unloaded and the system was cleaned by washing in dilute Alconox, multiple deionized water rinsings, and air drying. The canisters were then repacked with similar ingredients and procedures as those used in PFP Test No. 1.

A new biological filter was installed. The activated charcoal canister was again packed with a mixed bed of activated charcoals, (1063 cm^3 of Westvaco's Nuchar WV-G and 708 cm^3 of Union Carbides Columbia LCJ) plus a mixed bed of ion exchange resins (482 cm^3 of Amberlite IR-120, 359 cm^3 of Amberlite IRA-402, and 239 cm^3 of Amberlite IR-45). Both silver halide cartridges were repacked with "fresh" silver salts. The deionizer was packed with a mixed bed of ion exchang resins (200 cm^3 of Amberlite IR-120, 150 cm^3 of Amberlite IRA-402 and 100 cm^3 of Amberlite IR-45).

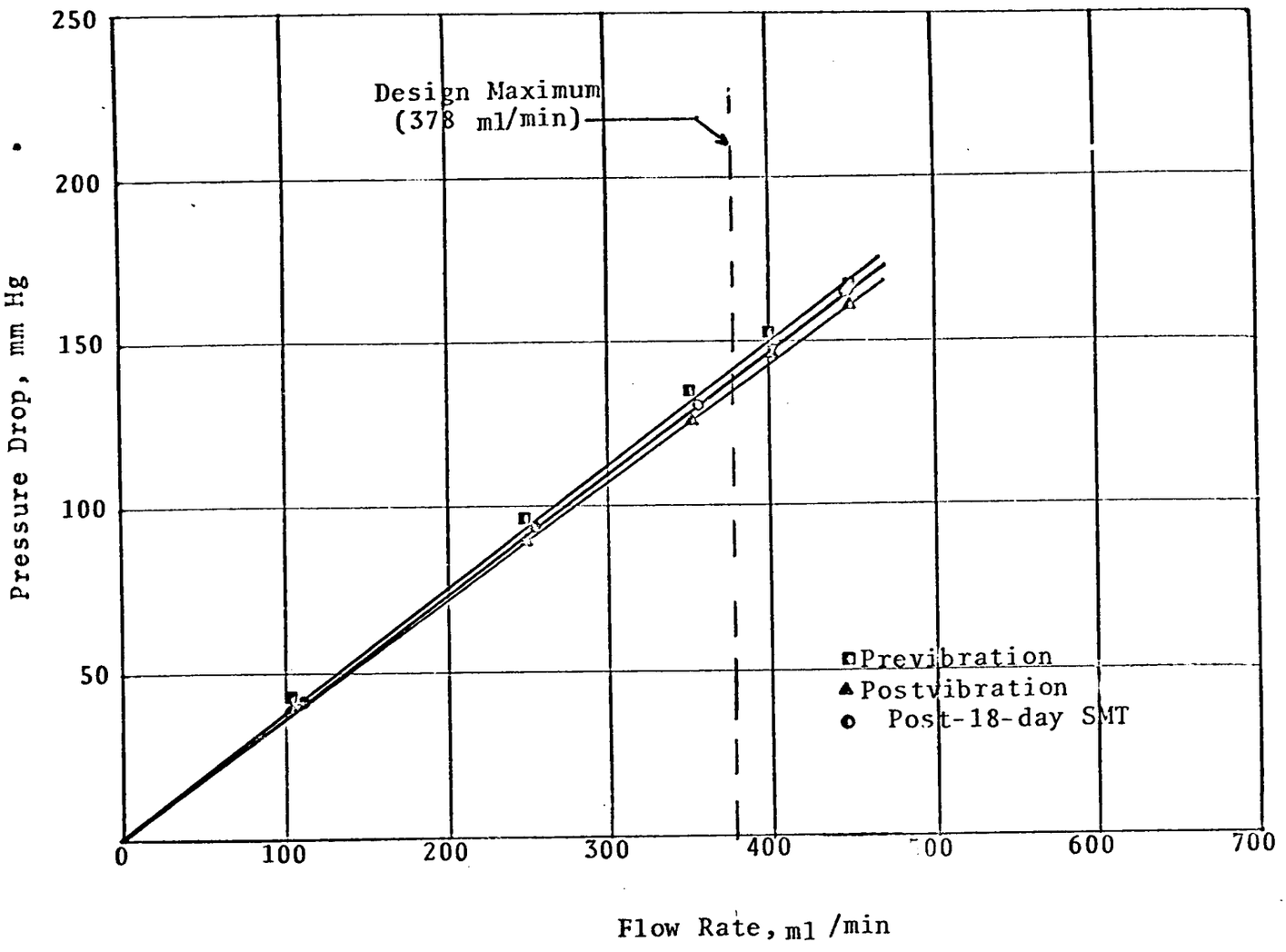


Figure 19 FLOW RESISTANCE FROM STORAGE TO OUTLET SIDE OF PFP

The packed assembly was then sterilized in a 344 - 347°K (160 - 165°F) water bath for 24 hours with 35 ml/min deionized water flushing.

6.3.2 Test Set-Up and Procedure

This test was performed with the same equipment used in PFP Test No. 1 (see Figure 17). The system processed "worst case" fuel cell water at ambient temperatures. Pseudomonas aeruginosa, Type IIIa and Bacillus subtilis were injected into three possible points of entry; (1) simulant, (2) storage tanks and (3) charcoal inlet. All simulant and product water flow rates were the same as those used in the first PFP test. Sampling procedures, technique and time also remained the same.

6.3.3 Test Results & Discussions

Table 8 lists the daily water quality characteristics of the PFP when processing "worst case" fuel cell water simulant. The tabulated "key" characteristics indicate that the system performed satisfactorily. The water quality was excellent and within all potability specifications for 13 days. On day 14 the pH dropped below the 6.0 requirement. At least 95% of the organics were removed during the first 13 days and 90% were still being removed after 18 days. As in the first PFP test, the silver bromide bypass cartridge dosed the deionizer effluent with silver ions below the 0.05 ppm level.

The PFP Bactericide System exhibited no chemical degradation due to the random vibration testing. Tabulated analyses of this test indicate no significant change to that observed in the first PFP test.

Table 9 lists the daily doses of bacteria injected and the plate counts on various sample points. On test days 1, 4 and 7 when the simulant was contaminated, the biological filter excluded the bacteria from the system. On test days 2, 3, 5 and 6, when Pseudomonas aeruginosa and Type IIIa bacteria were introduced into the system downstream of the biological filter, the tabulated results indicated that both the stored and product water were sterile (i.e., $< 1/200$ ml). The silver ion dose (ca. 1 ppm) was bactericidal against the infusion of $3 \pm 1 \times 10^9$ Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less.

On the basis of test day 8, the results indicate a three log reduction of Bacillus subtilis in 24 hours; i.e., from $3 \pm 1 \times 10^5$ per 63 liters or $10^{0.7}$/ml to 1/100 ml or 10^{-2}/ml. It is evident the Bacillus subtilis injected into the activated charcoal bed on test day 9 were filtered-out by the charcoal or the ion exchange bed or AgCl-glass bead bed downstream and were subsequently killed off because no bacteria were detected in the

Table 8 PFP TEST No.2 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	7.3	24.0	14.5	140	8.1	2.0	8.0	70	<0.010
	Stored 4th*	7.2	370.0	0.34	20	<1.0	<1.0	<1.0	1	1.16
	Stored 21st*	7.2	370.0	0.10	5	<1.0	<1.0	<1.0	1	1.20
	Product	7.1	760.0	0.11	<5	<1.0	<1.0	<1.0	1	0.042
2	Simulant	6.9	25.0	14.0	140	8.1	2.0	8.0	81	<0.010
	Stored 4th*	7.1	350.0	0.36	10	<1.0	<1.0	<1.0	26	1.24
	Stored 21st*	7.1	360.0	0.10	5	<1.0	<1.0	<1.0	1	1.22
	Product	7.1	740.0	0.06	<5	<1.0	<1.0	<1.0	1	0.040
3	Simulant	7.2	24.5	13.5	140	8.1	2.0	6.0	40	<0.010
	Stored 4th*	7.2	350.0	0.14	10	<1.0	<1.0	<1.0	1	1.18
	Stored 21st*	7.1	350.0	0.07	5	<1.0	<1.0	<1.0	1	1.18
	Product	7.1	720.0	0.06	<5	<1.0	<1.0	<1.0	1	0.040
4	Simulant	7.3	24.0	14.0	140	8.1	2.0	8.0	57	<0.010
	Stored 4th*	6.9	330.0	0.14	4	<1.0	<1.0	<1.0	14	1.20
	Stored 21st*	7.0	340.0	0.04	5	<1.0	<1.0	<1.0	1	1.16
	Product	7.1	650.0	0.04	<5	<1.0	1.0	<1.0	1	0.042
5	Simulant	6.8	24.5	13.5	140	8.1	3.0	6.0	45	<0.010
	Stored 4th*	6.9	340.0	0.14	5	<1.0	<1.0	<1.0	1	1.10
	Stored 21st*	6.9	340.0	0.05	5	<1.0	<1.0	<1.0	1	1.16
	Product	7.0	560.0	0.04	<5	<1.0	1.0	<1.0	1	0.044

* Denotes Hour

Table 8 Continued

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
6	Simulant	7.1	25.0	14.5	140	8.1	2.0	8.0	69	<0.010
	Stored 4th*	6.8	320.0	0.09	5	<1.0	<1.0	<1.0	5	1.16
	Stored 21st*	6.8	330.0	0.09	5	<1.0	<1.0	<1.0	4	1.24
	Product	7.0	480.0	0.04	<5	<1.0	1.5	1.0	3	0.040
7	Simulant	7.2	24.0	14.5	140	8.1	2.0	8.0	55	<0.010
	Stored 4th*	6.8	320.0	0.08	10	<1.0	<1.0	<1.0	9	1.20
	Stored 21st*	6.8	290.0	0.18	5	<1.0	1.0	<1.0	7	1.22
	Product	7.0	380.0	0.03	5	<1.0	1.5	<1.0	9	0.040
8	Simulant	7.3	24.0	14.0	140	8.1	2.0	8.0	53	<0.010
	Stored 4th*	6.8	290.0	0.41	10	1.5	1.0	<1.0	1	1.10
	Stored 21st*	6.8	270.0	0.17	5	1.0	1.5	1.0	1	1.16
	Product	7.0	330.0	0.09	5	<1.0	1.5	1.0	1	0.042
9	Simulant	7.3	24.0	15.0	140	8.1	2.0	8.0	46	<0.010
	Stored 4th*	6.8	190.0	0.39	20	2.0	2.5	<1.0	44	1.06
	Stored 21st*	6.9	160.0	0.14	10	1.5	2.0	1.0	1	1.06
	Product	7.0	210.0	0.07	10	<1.0	3.0	1.5	1	0.044
10	Simulant	7.3	24.0	14.5	140	8.1	2.0	8.0	100	<0.010
	Stored 4th*	6.5	110.0	0.45	20	2.0	2.0	<1.0	30	1.08
	Stored 21st*	6.6	120.0	0.16	20	1.5	2.0	1.0	7	1.02
	Product	6.9	140.0	0.06	20	<1.0	3.0	1.5	5	0.044

* Denotes Hour

Table 8 Continued

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
11	Simulant	6.9	24.5	14.0	140	8.1	2.0	6.0	58	<0.010
	Stored 4th*	6.6	110.0	0.35	10	2.0	2.0	1.0	2	1.06
	Stored 21st*	6.9	150.0	0.10	10	1.0	3.0	1.5	1	1.04
	Product	6.9	150.0	0.10	10	1.0	3.0	1.5	1	0.040
12	Simulant	6.8	25.5	14.5	140	8.1	2.0	6.0	69	<0.010
	Stored 4th*	6.6	110.0	0.38	10	2.5	2.0	1.0	30	1.04
	Stored 21st*	6.4	130.0	0.16	10	1.5	2.0	1.0	33	0.98
	Product	6.6	120.0	0.10	10	1.0	3.0	1.5	26	0.038
13	Simulant	6.8	24.5	14.5	140	8.1	2.0	6.0	81	<0.010
	Stored 4th*	5.6	140.0	0.37	10	1.0	6.0	<1.0	28	0.86
	Stored 21st*	5.6	160.0	0.14	10	1.0	6.0	<1.0	22	0.85
	Product	6.1	185.0	0.10	10	<1.0	3.0	<1.0	18	0.040
14	Simulant	6.8	24.5	15.0	140	8.1	3.0	6.0	64	<0.010
	Stored 4th*	5.7	115.0	0.26	20	1.5	6.0	<1.0	24	0.83
	Stored 21st*	5.6	115.0	0.12	15	1.5	6.0	<1.0	21	0.84
	Product	5.8	240.0	0.09	15	1.0	3.0	<1.0	14	0.040
15	Simulant	6.9	24.0	14.5	140	8.1	2.0	8.0	68	<0.010
	Stored 4th*	5.7	74.0	0.11	20	1.5	7.0	<1.0	26	0.74
	Stored 21st*	5.4	74.0	0.08	15	1.5	7.0	<1.0	26	0.76
	Product	5.6	240.0	0.04	15	1.0	3.5	<1.0	17	0.042

* Denotes Hour

Table 8 Concluded

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
16	Simulant	6.6	24.5	15.0	140	8.1	2.0	7.0	84	<0.010
	Stored 4th*	5.1	72.0	0.17	20	1.5	7.0	<1.0	16	0.68
	Stored 21st*	4.5	29.0	0.08	15	2.0	9.0	<1.0	12	0.65
	Product	5.4	230.0	0.05	15	1.0	3.5	<1.0	1	0.042
17	Simulant	6.5	25.0	14.0	140	8.1	2.0	6.0	51	<0.010
	Stored 4th*	4.1	21.0	0.28	20	2.0	12.0	<1.0	10	0.46
	Stored 21st*	3.9	18.5	0.26	15	2.0	14.0	<1.0	12	0.42
	Product	5.2	160.0	0.14	15	1.0	4.0	<1.0	4	0.038
18	Simulant	6.5	25.0	14.5	140	8.1	2.0	6.0	72	<0.010
	Stored 4th*	3.8	15.0	0.18	20	2.5	16.0	<1.0	10	0.28
	Stored 21st*	3.8	14.0	0.15	15	2.5	16.0	<1.0	11	0.26
	Product	4.9	120.0	0.07	15	1.5	7.0	<1.0	2	0.034

* Denotes Hour

Table 9 SUMMARY OF BACTERIOLOGIC ANALYSES FOR PFP TEST No.2

Test Day	Dose(1) Injection Point	Dose(1) Number & Specie	Simulant(2)	Sample Points: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant	$3\pm1x10^9$ P.a.	$3\pm1x10^4$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Storage Tanks	$3\pm1x10^9$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Charcoal Inlet	$3\pm1x10^9$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Simulant	$3\pm1x10^9$ IIIa	$3\pm1x10^4$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
5	Storage Tanks	$3\pm1x10^9$ IIIa	7/100ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
6	Charcoal Inlet	$3\pm1x10^9$ IIIa	3/100ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
7	Simulant	$3\pm1x10^5$ B.s.	$3\pm1x10^5$/ml	4	<1/200ml	23	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
8	Storage Tanks	$3\pm1x10^5$ B.s.	<1/200ml	4	6/100ml	22	2/100ml	23	4/100ml
				21	2/100ml	23	<1/200ml	24	1/100ml
9	Charcoal Inlet	$3\pm1x10^5$ B.s.	<1/200ml	4	<1/200ml	22	3/100ml	23	2/100ml
				21	<1/200ml	23	<1/200ml	24	12/100ml

(1) All doses injected during start up, 1st hour.
(2) All simulant samples taken during 24th hour.
(3) Outlet Valve

Table 9 Concluded

Test Day	Dose(1) Injection Point	Dose(1) Number & Species	Simulant(2)	Sample Points: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
10	Simulant	$3\pm1x10^5$ B.s.	$3\pm1x10^4$/ml	4	<1/200ml	22	<1/200ml	23	4/100ml
				21	<1/200ml	23	1/200ml	24	16/100ml
11	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
12	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
13	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
14	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
15	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
16	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
17	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile
18	None		Sterile	4	Sterile	22	Sterile	23	Sterile
				21	Sterile	23	Sterile	24	Sterile

(1) All Doses injected during start up, 1st hour.
(2) All simulant samples taken during 24th hour.
(3) Outlet Valve

stored water on days 9 to 18 inclusive. On test day 10 the Bacillus subtilis injected into the simulant were excluded by the biological filter.

Bacteria present in the system on test days 8,9,and 10 were Bacillus subtilis from the injection on day 8 into the storage tanks. Three days were required for the system to "cleanse" itself of Bacillus subtilis with the combination of dilution, flushing,and a 0.050 ppm silver ion dose.

On days 11 - 18, no injections were made but sterility determinations were performed on all samples by innoculation of thioglycolate broth. The tubes were incubated at 308°K (95°F) and inspected at 24 and 48 hours for turbidity. All samples were determined to be sterile indicating that the system "cleaned" itself on day 11.

On days 10, 11,and 12, a special sample was taken directly at the heater outlet connection. This water had been in the heater at 336°K (145°F) for 22 hours. The count was found to be $<$1/200 ml.

The bacteriological data in Table 9 indicates that the "worst case" fuel cell simulant with 100 ppm organics (20 ppm each of toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone, and xylenol) had no deleterious effects on Pseudomonas aeruginosa and /or Type IIIa. Samples withdrawn from the simulant tank 24 hours after bacteria injection were found to be within the range anticipated after dilution (i.e., $3 \pm 1 \times 10^9$ cell/94 liters or $3 \pm 1 \times 10^4$/ml).

It appears that the "worst case" fuel cell simulant with the 100 ppm of organics was a growth media for the Bacillus subtilis. Samples withdrawn 24 hours from the simulant tank on test days 7 and 10 were found to contain $3 \pm 1 \times 10^5$/ml and $3 \pm 1 \times 10^4$/ml, respectively. The samples by dilution should have only contained $3 \pm 1 \times 10^5$ spore/94 liters or 3 ± 1 spores/ml. The aerobic conditions in the simulant tank apparently germinated some of the spores to the vegetative form and proliferation occurred.

EXTENDED TESTING

The Breadboard Tests and the Preliminary Flight Prototype Tests reported in Sections 4 and 6 respectively were performed with a system designed to process "worst case" fuel cell water simulant as defined in Section 3. To perform this function the system included (1) a biological filter, (2) a canister of activated charcoals and ion exchange resins, (3) a silver chloride column, (4) a deionizer, and (5) a silver bromide column.

Fuel cell water constituents govern the design of the water treating system. The particulates, organics, dissolved solids and chlorides affect the number of components in the design. Recently, new information has been collected on fuel cell water from two candidate fuel cells (Pratt & Whitney and General Electric). This new data indicates that all of the components listed above which are required to convert "worst case" fuel cell water, may not be required to treat "real" fuel cell water.

Contract NAS 9-12792 was amended by adding the following to paragraph 3.2.6 of the Statement of Work.

> "Following completion of the 'worst case fuel cell water' system tests, the preliminary flight prototype system components shall be tested with various grades of simulated fuel cell water to define the minimum bactericide system requirements for processing 'cleaner' fuel cell water. The useful life and dynamic performance of each component shall be determined. A minimum of six simulated mission tests shall be performed using three different compositions of simulated fuel cell water (with and without chlorides), and bacteria shall be injected daily. Sufficient water sampling and analyses shall be performed to verify product water potability and to determine when system useful life is exceeded."

7.1 Extended Tests without Chlorides in the Simulant

Three simulated mission tests were performed with a modified PFP system processing Pratt & Whitney type fuel cell water simulant (i.e., without chlorides). The objectives were to determine the performance and the operational life of the modified PFP system while treating different concentrations of the Pratt & Whitney type fuel cell water simulant.

7.1.1 Pratt & Whitney FCW Simulant Definition

The constituents along with their respective concentrations for "worst case" Pratt & Whitney type fuel cell water simulant are listed in Table 10. The two other concentrations were made by dilution. The "mid case" concentration

Table 10 PRATT & WHITNEY WORST CASE FCW SIMULANT COMPOSITION

Cationic Species	Concentration (ppm)
Cadmium	0.01
Copper	1.00
Iron	0.30
Lead	0.05
Magnesium	0.17
Manganese	0.05
Mercury	0.005
Nickel	0.05
Potassium	0.54
Sodium	3.30
Titanium	0.20
Zinc	5.00
Anionic Species	
Chromate	0.1 ($Cr^{+}6$ = .05)
Fluoride	1.6
Nitrate	0.04
Selenite	0.08 (Se = .05)
Sulfate	14.6
Particulate	
Silica (50 - 100 μ)	100
Bacteria (1 - 10 μ)	100,000/liter
Other	
Total Organics	100 (50/10)
pH (pH units)	8.0

employed was two-thirds "worst case" ionic species and particulates with 50 ppm organics. The "low case" concentration employed was one-third "worst case" ionic species and particulates with 10 ppm organics.

The pH of the fuel cell water simulant was adjusted by the addition of a standard alkaline solution (sodium hydroxide) to the specified pH.

7.1.2 Test Set-Up and Procedure

Figure 20 shows the arrangement of components used in these tests. The components that define this water treating system in the order of their use are as follows: (1) a particulate filter, (2) a silver chloride column, and (3) a deionizer with a partial bypass. A particulate filter was used in lieu of a biological filter because there were no beds of charcoal or ion exchange resins to protect from biological contaminants before the AgCl column. Since there were no chlorides in the simulant to suppress the solubility of AgCl, no ion exchange resins were utilized upstream of the AgCl. Activated charcoals were purposely omitted to determine the effects of various concentrations of organics in the FCW simulant on the performance of the modified PFP system. The AgBr column was obviated by incorporating a partial bypass in the deionizer to retain a residual silver ion dose of approximately 0.05 ppm in the product water.

A one micron particulate in-depth filter (Service Filtration Company Housing No. ABSLU6½ and their filter Cartridge No. VIA6U) was installed into the test equipment upstream of the PFP package. The PFP's biological filter canister, activated charcoal/ion exchange canister, and silver bromide canister remained empty. The silver chloride canister and the deionizer were the same as described in Section 5, except, that a partial bypass was incorporated into the deionizer. The internal bypass in the deionizer was a 38.5 cm (15-1/8 inch) length of silastic medical grade tubing with a 2.16 mm (0.085 inch) OD and a bore of 1.015 mm (0.040 inch), positioned in between the Pyrex wools.

The modified PFP system processed three concentrations ("worst case", "mid case" and "low case") Pratt & Whitney type fuel cell water simulant to exhaustion; i.e., until the product water went out of pH potability specifications. Pseudomonas aeruginosa, Type IIIa, and Bacillus subtilis were injected into two possible points of entry, namely, the simulant and the storage tanks, during the first six test days in respective order. On the seventh test day no injection was made; day 7 was used to evaluate the effect of longer retention time on the Bacillus subtilis spores. Since the tests were performed until

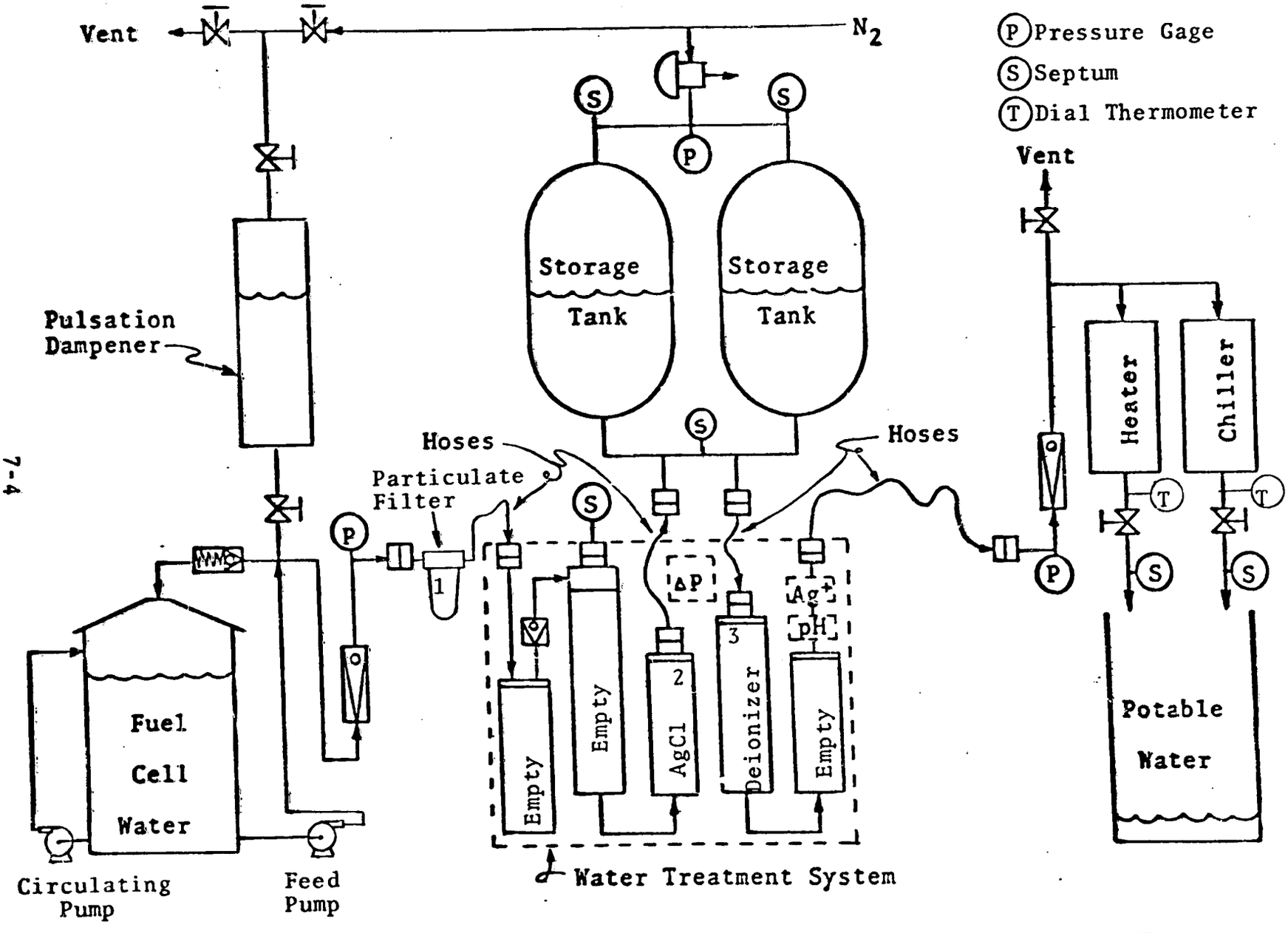


Figure 20 FLOW SCHEMATIC FOR EXTENDED TESTS WITHOUT CHLORIDES IN SIMULANT

exhaustion of the system, the sequence was repeated on those days succeeding day 7. All simulant and product water flow rates were the same as those used in the previous testing. The modified PFP system was refurbished and resterilized for the "mid case" and "low case" tests.

7.1.3 Extended Test No. 1 - Results & Discussion

In Extended Test No. 1, the system processed "worst case" Pratt & Whitney type fuel cell water at ambient temperatures, 294 - 297°K (70 - 75°F), during the period February 19 to February 26, 1973. Table 11 lists the daily water quality characteristics. The tabulated results indicate that the ion exchange resins absorbed 60% of the organics during the first three days and virtually none thereafter. The product water pH fell below potability specification on Test Day No. 5. The silver ion concentrations were approximately 1.1 ppm in the stored water and approximately 0.05 ppm in the product water.

Table 12 lists the daily doses of bacteria injected and the plate counts performed on various samples. The in-depth one micron particulate filter cannot effectively exclude bacteria. On test days 1, 2, 3, and 4 when Pseudomonas aeruginosa and Type IIIa bacteria were introduced into simulant and storage tanks, the tabulated results indicate that both the stored and product water were sterile (i.e., <1 cell/200 ml). The silver ion dose (ca. 1 ppm) was bactericidal against the infusion of $3 \pm 1 \times 10^{10}$ Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less.

On test day No. 5, when the simulant was contaminated, Bacillus subtilis breakthrough occurred. It is clearly evident that the in-depth one micron filter can not exclude bacteria. It is also apparent that some of the Bacillus subtilis were retained by the particulate filter, but the degree of exclusion is unknown. Assuming that one-half of the Bacillus subtilis passed through the particulate filter, the data for test day 5 indicates a five log reduction of Bacillus subtilis in 24 hours at ambient temperatures with a 1 ppm silver ion dose - i.e., from $1.5 \pm 1 \times 10^4$/ml or $10^{4.2}$/ml to 17/100 ml or $10^{-0.8}$/ml. The maximum count obtained (the 24th hour sample) was used to determine the reduction rate; during test day 5 the aerobic conditions caused proliferation of the Bacillus subtilis. On the basis of test day 6, when bacteria were injected into the storage tank, the data indicates a 2.4 log reduction of Bacillus subtilis in 21 hours at ambient temperatures with a 1 ppm silver ion dose - i.e., 3 ± 10^5/63 liters or $10^{0.7}$/ml to 2/100 ml or $10^{-1.7}$/ml.

Table 11 EXTENDED TEST No.1 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	7.8	25.5	13.7	140	<1.0	2.5	5.0	80	<0.010
	Stored 4th*	7.7	27.0	2.4	135	<1.0	2.5	4.5	38	1.14
	Stored 21st*	7.7	27.0	2.4	135	<1.0	2.5	4.5	34	1.18
	Product	7.3	200.0	0.85	40	<1.0	<1.0	<1.0	4	0.055
2	Simulant	7.8	25.5	13.0	140	<1.0	2.5	5.0	73	<0.010
	Stored 4th*	7.7	25.5	1.8	130	<1.0	2.0	4.5	34	1.14
	Stored 21st*	7.7	25.5	1.8	130	<1.0	2.0	4.5	23	1.16
	Product	7.0	180.0	0.67	40	<1.0	1.0	1.0	2	0.055
3	Simulant	7.7	26.0	13.4	140	<1.0	2.5	4.5	78	<0.010
	Stored 4th*	7.7	25.0	0.9	110	<1.0	2.5	4.0	49	1.12
	Stored 21st*	7.7	25.0	0.9	110	<1.0	2.5	4.0	41	1.16
	Product	7.5	56.0	0.42	40	1.0	2.5	4.5	24	0.052
4	Simulant	7.8	25.5	13.8	140	<1.0	2.5	5.0	86	<0.010
	Stored 4th*	7.7	23.0	0.86	110	<1.0	2.5	4.0	46	1.14
	Stored 21st*	7.7	23.0	0.86	110	<1.0	2.5	3.5	29	1.18
	Product	7.5	50.0	0.40	100	1.0	3.0	4.0	20	0.052
5	Simulant	8.2	20.0	14.0	140	<1.0	<1.0	12.0	82	<0.010
	Stored 4th*	8.2	19.5	0.88	110	<1.0	<1.0	8.0	69	1.10
	Stored 21st*	8.2	19.5	0.90	110	<1.0	<1.0	8.0	70	1.16
	Product	5.9	36.0	0.40	100	1.0	8.0	<1.0	27	0.055

* Denotes Hour

Table 11 Concluded

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
6	Simulant	8.2	20.0	13.5	140	<1.0	<1.0	12.0	98	<0.010
	Stored 4th*	8.2	19.5	0.85	110	<1.0	<1.0	8.0	51	1.16
	Stored 21st*	8.1	19.5	0.85	110	<1.0	<1.0	8.0	53	1.18
	Product	4.4	20.0	0.30	100	1.0	12.5	<1.0	25	0.052
7	Simulant	8.2	20.0	13.5	140	<1.0	<1.0	12.0	84	<0.010
	Stored 4th*	8.1	19.5	0.60	100	<1.0	<1.0	7.0	45	1.10
	Stored 21st*	8.1	19.5	0.60	100	<1.0	<1.0	7.0	44	1.14
	Product	3.9	18.0	0.40	100	1.0	14.5	<1.0	22	0.05

* Denotes Hour

Table 12 SURVEY OF BACTERIA FROM [illegible]

Dose (1)	Number of Colonies Specific	Stained(2)	Stored Water Day	Colonies			
1	5.1×10^{10} P.	3.1×10^{5}/ml	4	<1/200ml	22	<1/	
			21	<1/200ml	25	<1/	
2	5.1×10^{10} P.S.	<1/200ml	4	<1/200ml	22	<1/	
			21	<1/200ml	25	<1/	
3	3×10^{10} D.S.	3.1×10^{5}/ml	4	<1/200ml	22	<1/	
			21	<1/200ml	25		
4	3.1×10^{10} D.S.	<1/200ml	4	<1/200ml	22	<1/	
			21	<1/200ml	25	<1/	
5	3.1×10^{5} D.S.	3.1×10^{5}/ml	4	<1/200ml	22		
			21	4/100ml	25		
6	3.1×10^{5} P.S.	9/100ml	4	4/10	22	3/	
			21	2/10	25	/1	
7		<1/200ml	4	1/1	22		
			21	<1/20	25		

(1) [illegible] during start-up (1st [illegible]).

(2) [illegible] after during 24th hour.

(3) [illegible]

Table 13 EXTENDED TEST No.2 [illegible] QUALITY CHA[illegible]

Test Period	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl⁻ (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag (ppm)
[illegible]	Sea Plant	8.1	23.0	12.5	70	<1.0	<1.0	10.0	[illegible]	<0.0[illegible]
	Stored 4th*	8.1	23.5	2.0	50	<1.0	<1.0	8.0	25	1.[illegible]
	Stored 21st*	8.1	23.5	2.0	50	<1.0	<1.0	8.0	25	1.[illegible]
	Product	7.1	210.0	0.14	10	<1.0	<1.0	<1.0	[illegible]	0.0[illegible]
[illegible]	Sea Plant	8.1	24.0	11.0	70	<1.0	<1.0	12.0	[illegible]	<0.0[illegible]
	Stored 4th*	7.9	26.0	1.3	50	<1.0	<1.0	6.0	[illegible]	1.[illegible]
	Stored 21st*	7.9	26.0	1.2	50	<1.0	<1.0	6.0	[illegible]	1.[illegible]
	Product	6.9	215.0	0.11	35	<1.0	1.0	<1.0	26	0.0[illegible]
[illegible]	Sea Plant	8.2	24.0	12.0	70	<1.0	<1.0	10.0	[illegible]	<0.0[illegible]
	Stored 4th*	7.9	27.0	1.2	50	<1.0	<1.0	6.0	[illegible]	1.[illegible]
	Stored 21st*	7.9	27.5	1.4	60	<1.0	[illegible].0	6.0	[illegible]	[illegible]
	Product	6.7	170.0	0.10	60	<1.0	1.0	<1.0	22	0.0[illegible]
[illegible]	Sea Plant	8.1	26.0	10.4	70	<1.0	<1.0	10.0	[illegible]	<0.0[illegible]
	Stored 4th*	7.9	27.0	1.1	60	<1.0	[illegible].0	6.0	[illegible]	0.9[illegible]
	Stored 21st*	7.9	27.0	1.2	60	<1.0	[illegible].0	6.0		0.9[illegible]
	Product	6.5	170.0	0.10	60	<1.0	1.0	<1.0	[illegible]	0.0[illegible]
[illegible]	Sea Plant	8.1	25.0	12.8	70	<1.0	[illegible].0	12.0	[illegible]	<0.0[illegible]
	Stored 4th*	8.0	25.0	1.1	60	<1.0	<1.0	6.0	[illegible]	0.[illegible]
	Stored 21st*	8.0	26.0	1.1	50	<1.0	<1.0	6.0	[illegible]	0.[illegible]
	Product	6.4	160.0	0.12	60	<1.0	2.0	<1.0	26	0.0[illegible]

[illegible] Plant Room

Table 15 Concluded

Test Day	Sample Name	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag+ (ppm)
6	Sealant	8.0	26.0	10.2	70	<1.0	<1.0	10.0	16	<0.010
	Stored 4th*	7.9	26.5	0.78	70	<1.0	<1.0	6.0	12	0.90
	Stored 21st*	7.9	26.5	0.74	70	<1.0	<1.0	6.0	8	0.90
	Product	6.1	90.0	0.10	70	1.0	3.0	<1.0	0	0.010
7	Sealant	8.0	24.0	10.4	70	<1.0	<1.0	10.0	55	<0.010
	Stored 4th*	7.8	25.0	0.76	60	<1.0	<1.0	6.0	[illegible]	0.92
	Stored 21st*	7.8	25.0	0.76	60	<1.0	<1.0	6.0	[illegible]	0.92
	Product	4.9	27.0	0.10	60	1.0	12.0	<1.0	[illegible]	0.010
8	Sealant	8.0	24.0	10.8	70	<1.0	<1.0	14.0	[illegible]	<0.010
	Stored 4th*	7.8	24.5	1.0	60	<1.0	1.0	8.0	[illegible]	0.90
	Stored 21st*	7.8	25.0	1.4	60	<1.0	<1.0	8.0	[illegible]	0.90
	Product	4.5	18.5	0.14	60	1.0	16.0	<1.0	[illegible]	0.010

* [illegible] Days

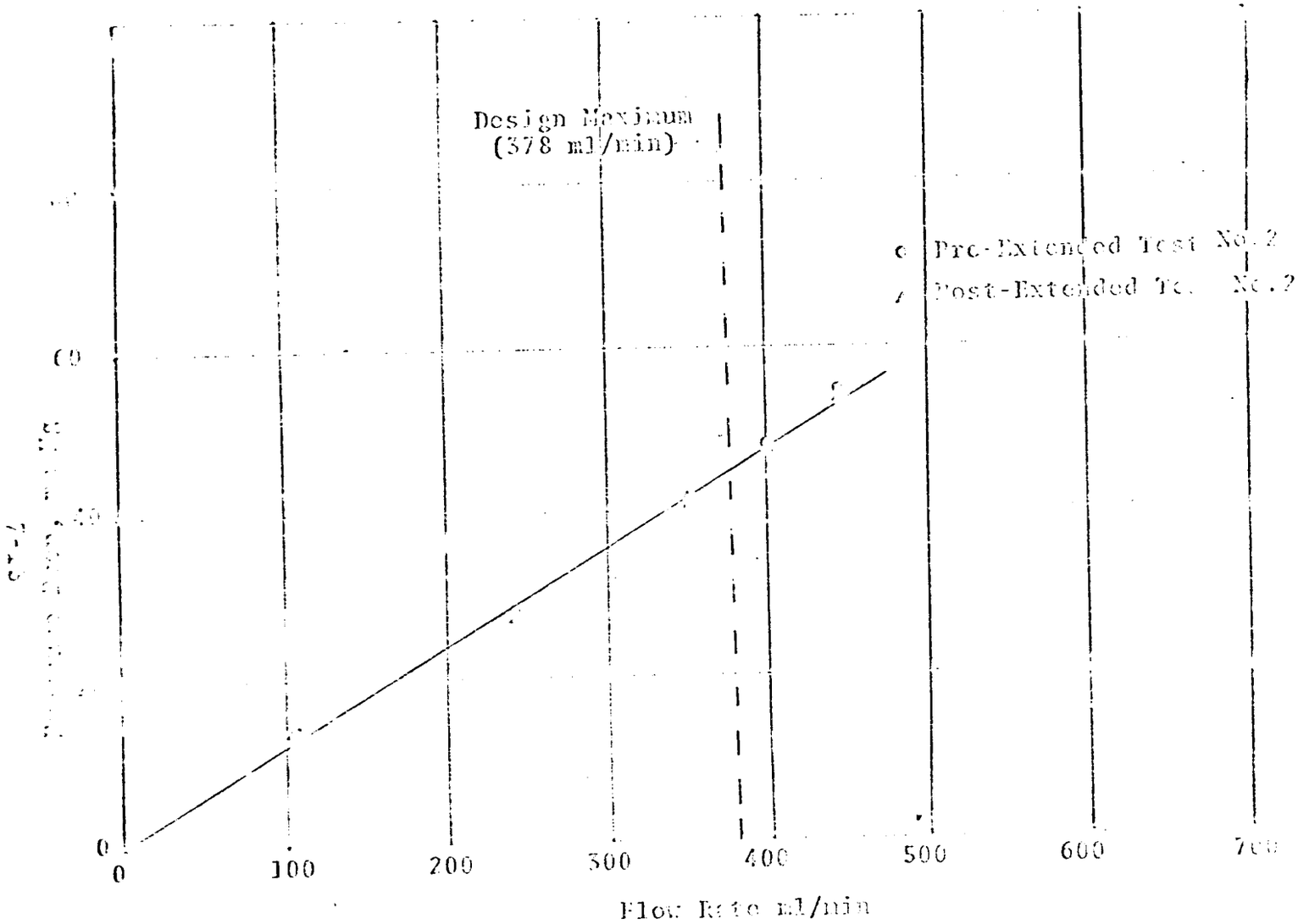


Figure 22 FLOW RESISTANCE OF DEIONIZER WITH BYPASS

Table 14 lists the [illegible] and the plate counts performed [illegible] this table indicates that the bio[illegible] during Extended Test No. 2 were similar to the results of Extended Test No. 1. They are as follows:

A. A 1 ppm silver ion dose was [illegible] against the infusion of 3 x 1 x 10^{10} (i.e., 3 x 1 x 10^{7}/ml) Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less.

B. An in-depth one micron particulate filter cannot effectively exclude bacteria.

C. A 1 ppm silver ion dose at ambient temperatures reduced Bacillus subtilis counts by up to 5 orders of magnitude in 24 hours.

D. A 0.50 ppm silver ion dose was more efficacious at elevated temperatures, 332 - 336°K (135 - 145°F). When breakthrough and/or contamination occurred, the Bacillus subtilis counts at the hot water outlet valve were lower than at the cold water outlet valve.

E. The simulant with 50 ppm organics did not affect either Pseudomonas aeruginosa or Type IIIa bacteria. Counts were found to be within the range anticipated.

F. Under aerobic conditions the simulant with 50 ppm organics was synergistic to the proliferation of Bacillus subtilis.

Bacteria present in the system on test days 7 and 8 were Bacillus subtilis from the injections on days 5 and 6. The deionizer became contaminated on days 5 and 6 and the bacteria present in the cold water outlet valve were Bacillus subtilis that were diluted and flushed out.

7.1.5 Extended Test No. 3 - Results and Discussion

In Extended Test No. 3, the system processed "low case" Pratt and Whitney type fuel cell water simulant at ambient temperatures, 294 - 297°K (70 - 75°F), during the period March 26 to April 5, 1973. Table 15 lists the daily water quality characteristics. The tabulated results show no discernible absorption of the organics by the ion exchange resins as indicated by the COD analyses. The product water pH fell below potability specifications on test day 11. The silver ion concentrations were approximately 1 ppm in the stored water and approximately 0.05 ppm in the product water.

Table 14 SUMMARY OF BACTERIOLOGIC ANALYSES FOR EXTENDED TEST No.

Test Day	Dose(1) Injection Point	Dose(1) Number & Specie	Sample Point: Simulant(2)	Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant	$4\pm1\times10^{10}$ P.a.	$4\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Storage	$4\pm1\times10^{10}$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Simulant	$3\pm1\times10^{10}$ IIIa	$3\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Storage	$3\pm1\times10^{10}$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
5	Simulant	$3\pm1\times10^{5}$ B.s.	$3\pm1\times10^{4}$/ml	4	2/100ml	22	1/100ml	23	9/100ml
				21	4/100ml	23	2/100ml	24	32/100
6	Storage	$3\pm1\times10^{5}$ B.s.	<1/200ml	4	<1/200ml	22	<1/200ml	23	1/100ml
				21	<1/200ml	23	<1/200ml	24	2/100ml
7	None		<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	5/100ml
8	Simulant	$3\pm1\times10^{10}$ P.a.	$3\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	23/100ml
				21	<1/200ml	23	<1/200ml	24	26/100ml

(1)All doses injected during start-up (1st hour).

(2)All simulant samples taken during 24th hour.

(3)O.V. = Outlet Valve

* Bacillus subtilis

Table 15 EXTENDED TEST No.3 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	8.3	34.0	2.8	10	<1.0	<1.0	9.0	58	<0.010
	Stored 4th*	8.2	36.0	0.21	10	<1.0	<1.0	6.0	10	0.92
	Stored 21st*	8.2	36.0	0.24	10	<1.0	<1.0	6.0	20	0.94
	Product	7.5	240.0	<0.10	10	<1.0	<1.0	<1.0	8	0.052
2	Simulant	8.1	38.0	1.4	10	<1.0	<1.0	8.0	17	<0.010
	Stored 4th*	8.0	44.0	0.34	15	<1.0	<1.0	6.0	10	0.94
	Stored 21st*	8.0	44.0	0.28	15	<1.0	<1.0	6.0	10	0.9[illegible]
	Product	7.4	280.0	<0.10	10	<1.0	1.0	<1.0	7	0.0[illegible]
3	Simulant	8.2	34.0	3.8	10	<1.0	<1.0	10.0	15	<0.01[illegible]
	Stored 4th*	8.1	37.0	0.76	10	<1.0	<1.0	7.0	12	0.9[illegible]
	Stored 21st*	8.1	36.5	0.68	15	<1.0	<1.0	7.0	13	0.96
	Product	7.4	280.0	<0.10	10	<1.0	1.0	1.0	10	0.050
4	Simulant	8.3	40.0	2.1	10	<1.0	<1.0	8.0	30	<0.010
	Stored 4th*	8.2	42.0	0.24	10	<1.0	<1.0	6.0	26	0.92
	Stored 21st*	8.2	42.0	0.18	10	<1.0	<1.0	6.0	26	0.9[illegible]
	Product	7.2	270.0	<0.10	15	<1.0	1.2	1.0	[illegible]	0.0[illegible]
5	Simulant	8.1	40.0	3.7	10	<1.0	<1.0	8.0	53	<0.0[illegible]
	Stored 4th*	8.0	44.0	0.19	10	<1.0	<1.0	6.0	2	0.9[illegible]
	Stored 21st*	8.0	44.0	0.14	10	<1.0	<1.0	6.0	2	0.92
	Product	7.2	255.0	<0.10	10	<1.0	1.2	1.0	3	0.0[illegible]

* Denotes Hour

Table 35 Concluded

Test Day	Sample Matrix	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag+ (ppm)
6	Simulant	8.1	37.0	3.6	10	<1.0	<1.0	8.0	8	<0.010
	Stored 4th*	8.0	39.0	0.48	10	<1.0	<1.0	6.0	3	0.90
	Stored 21st*	8.0	40.0	0.32	10	<1.0	<1.0	6.0	8	0.94
	Product	7.1	210.0	<0.10	15	<1.0	1.4	1.0	0	0.018
7	Simulant	8.2	37.0	3.2	10	<1.0	<1.0	8.0	32	<0.010
	Stored 4th*	8.1	39.0	0.32	10	<1.0	<1.0	6.0	20	0.90
	Stored 21st*	8.1	40.0	0.28	10	<1.0	<1.0	6.0	20	0.92
	Product	7.0	200.0	<0.10	10	<1.0	1.4	1.0	2	0.050
8	Simulant	8.0	40.0	4.4	10	<1.0	<1.0	8.0	88	<0.010
	Stored 4th*	7.9	42.0	0.28	10	<1.0	<1.0	6.0	11	0.90
	Stored 21st*	7.9	41.0	0.18	10	<1.0	<1.0	6.0	19	0.90
	Product	6.8	200.0	<0.10	10	<1.0	2.0	1.0	12	0.050
9	Simulant	8.2	36.0	4.6	10	<1.0	<1.0	10.0	30	<0.010
	Stored 4th*	8.0	38.0	0.36	10	<1.0	<1.0	7.0	12	0.92
	Stored 21st*	8.0	39.0	0.22	10	<1.0	<1.0	6.0	3	0.90
	Product	6.6	110.0	<0.10	10	<1.0	2.0	1.0	4	0.048
10	Simulant	8.0	40.0	4.8	10	<1.0	<1.0	8.0	23	<0.010
	Stored 4th*	7.9	42.0	0.38	10	<1.0	<1.0	6.0	22	0.92
	Stored 21st*	7.9	42.0	0.29	15	<1.0	<1.0	6.0	24	0.90
	Product	6.1	62.0	<0.10	10	<1.0	3.0	<1.0	0	0.046
11	Simulant	8.0	40.0	4.4	10	<1.0	<1.0	8.0	30	<0.010
	Stored 4th*	7.9	42.0	0.40	10	<1.0	<1.0	6.0	18	0.90
	Stored 21st*	7.9	42.0	0.18	10	<1.0	<1.0	6.0	16	0.90
	Product	5.3	44.0	<0.10	10	<1.0	10.0	<1.0	4	0.046

* [illegible]s Hour

Figures 23 and 24 show the hydraulic characteristics of the system before and after Extended Test No. 3. The data indicates no discernible change in pressure drop across any of the components as a result of operating eleven days at "low cube" conditions.

Table 16 lists the daily doses of bacteria injected and the plate counts performed on various samples. The data in this table indicates that the biological results obtained during Extended Test No. 3 were similar to the results of Extended Tests No's 1 and 2. They are as follows:

A. A 1 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $3 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less.

B. An in-depth one micron particulate filter cannot effectively exclude bacteria.

C. A 1 ppm silver ion dose at ambient temperatures reduced Bacillus subtilis counts by up to 5 orders of magnitude in 24 hours.

D. A 0.050 ppm silver ion dose was more efficacious at elevated temperatures, 332 - 336°K (135 - 145°F). When breakthrough and/or contamination occurred, the Bacillus subtilis counts at the hot water outlet valve were lower than at the cold water outlet valve.

E. The simulant with 10 ppm organics did not affect either Pseudomonas aeruginosa or Type IIIa bacteria. Counts after 24 hours were found to be within the range anticipated.

F. Under aerobic conditions the simulant with 10 ppm organics was synergistic to the proliferation of Bacillus subtilis.

Bacteria present in the system on test days 7, 8, 9, 10 and 11 were Bacillus subtilis from the injections on days 5 and 6. The deionizer became contaminated on days 5 and 6 and the bacteria present in the stored water on days 7 and 8 and in the cold water outlet valve were Bacillus subtilis that were diluted and flushed out.

7.2 Extended Tests with Chlorides in the Simulant

Two simulated mission tests were performed with a modified PWP system processing General Electric type fuel cell water simulant (i.e., with chlorides). The objectives were to determine the performance and operational life of the modified PWP system while treating different concentrations of the General Electric type fuel cell water simulant.

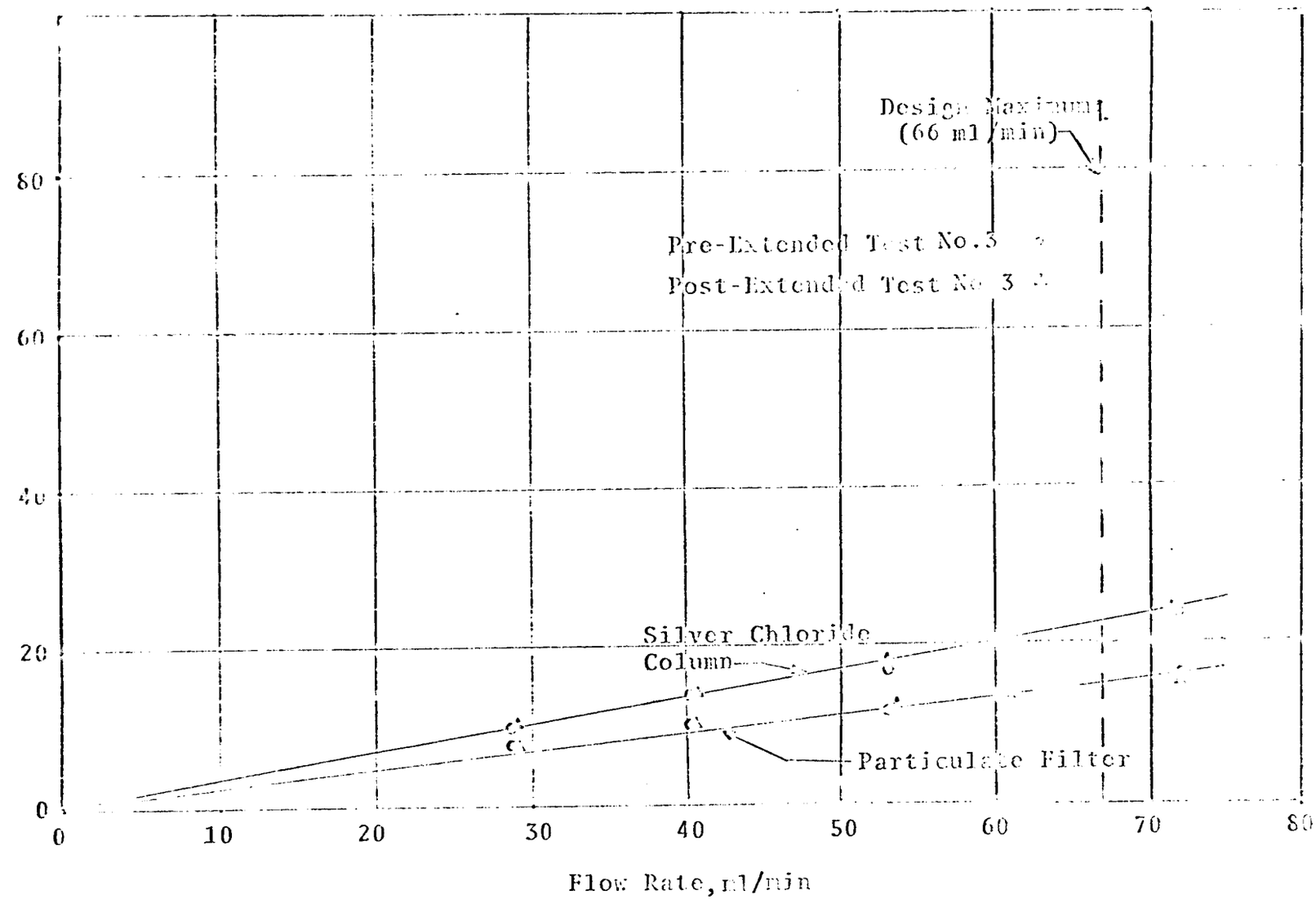


Figure 23 FLOW RESISTANCE OF PARTICULATE FILTER AND SILVER CHLORIDE COLUMN

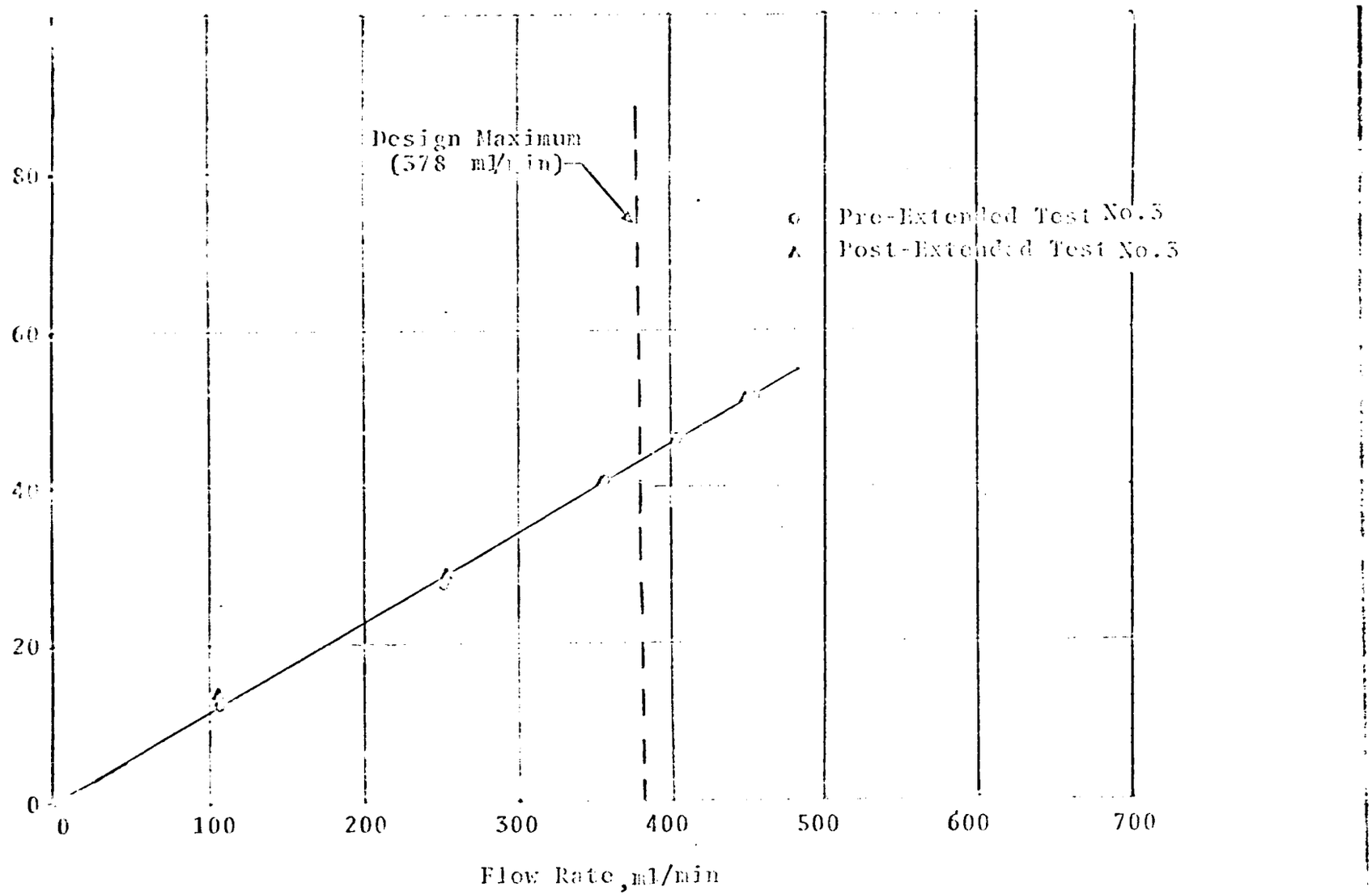


Figure 24 FLOW RESISTANCE OF DEIONIZER WITH BYPASS

Table 16 SUMMARY OF BACTERIOLOGIC ANALYSES FOR EXTENDED TEST No.5

Test	Doses(1) Injection Point	Number & Species	Simulant(2)	Sample Points: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V. Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant	$3\pm1\times10^9$ P.a.	$3\pm1\times10^5$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	25	<1/200ml	24	<1/200ml
2	Storage	$3\pm1\times10^9$ P.a.	1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	25	<1/200ml	24	<1/200ml
3	Simulant	$3\pm1\times10^9$ IIIa	$3\pm1\times10^5$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	25	<1/200ml	24	<1/200ml
4	Storage	$3\pm1\times10^9$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	25	<1/200ml	24	<1/200ml
5	Simulant	$3\pm1\times10^5$ B.s.	$3\pm1\times10^4$/ml	4	2/100ml	22	1/100ml	23	2/100ml
				21	2/100ml	25	1/100ml	24	1/100ml
6	Storage	$3\pm1\times10^5$ B.s.	<1/200ml	4	7/100ml	22	2/100ml	23	18/100ml
				21	9/100ml	25	4/100ml	24	9/100ml
7	None		<1/200ml	4	<1/200ml	22	3/100ml*	23	1/100ml*
				21	2/100ml*	25	<1/200ml	24	2/100ml*
8	Simulant	$3\pm1\times10^9$ P.a.	$3\pm1\times10^5$/ml	4	1/100ml*	22	<1/200ml	23	<1/200ml
				21	2/100ml*	25	<1/200ml	24	<1/200ml
9	Storage	$3\pm1\times10^9$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	3/100ml
				21	<1/200ml	25	<1/200ml	24	7/100ml*

(1) All doses injected during start-up, (1st hour).

(2) All simulant samples taken during 24th hour.

(3) O.V. = Outlet Valve

* Bacillus subtilis

Table 6 Concluded

Doses(1)			Sample Points					
Test	Injection Point	Number & Specie	Simulant(2)	Stored Water		Hot O.V.(3)	Cold O.V.	
				Hr	Count	Hr	Count	Hr	Count
10	Start	$3\pm1 \times 10^9$ IIIa	$3\pm1 \times 10^5$/ml	4	<1/200ml	22	<1/200ml	25	2/100ml
				21	<1/200ml	25	<1/200ml	28	1/100ml
11	Storage	$3\pm1 \times 10^9$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	25	2/100ml
				21	<1/200ml	25	<1/200ml	28	1/100ml

(1) All doses injected during start-up,(1st hour).

(2) All simulant samples taken during 24th hour.

(3) O.V. = Outlet Valve

* Bacillus subtilis

7.2.1 [illegible]

[illegible] respective concentrations [illegible] "low case" concentration [illegible] "worst case" [illegible] 16 ppm organics.

The pH of the feed water simulant was adjusted to the specified pH by the addition of a standard acid solution (sulfuric acid).

7.2.2 Test Setup and Procedure

Figure 25 shows the arrangement of components in these tests. The components that define this water treating system in the order of their use are as follows: (1) a biological filter, (2) an ion exchange canister, (3) a silver chloride column, and (4) a deionizer with a partial bypass. Since there were 12 ppm chlorides in the "worst case" FCW simulant, an ion exchange resin bed was employed upstream of the AgCl column so that a 1 ppm dose of silver ions could be obtained in the stored water. A biological filter was used in lieu of a particulate filter, to protect this ion exchange resin bed from biological contaminants. Activated charcoals were purposely omitted to determine the effects of various concentrations of organics in the FCW simulant on the performance of the modified PFP system. The AgBr Column was obviated by incorporating a partial bypass in the deionizer to retain a residual silver ion dose of approximately 0.05 ppm in the product water.

The biological filter, the silver chloride canister, and the deionizer were the same as described in Section 5, except that a partial bypass was again incorporated into the deionizer. As in the Extended Tests without chlorides, the internal bypass in the deionizer was a 38.5 cm (15-1/8 inch) length of silastic medical grade tubing, with a 2.16 mm (0.085 inch) ID and a bore of 1.016 mm (0.040 inch), positioned in between the Pyrex wools. The PFP's silver bromide canister remained empty.

The activated charcoal and ion exchange resin canister contained only a mixture of ion exchange resins; the same volume and type of resins as described in Section 5. The resin bed was supported by a 20.4 cm (10-3/8 inch) length of schedule 40, 3.81 cm (1-1/2 inch) PVC Briscopipe wedged between the retaining screens and end plate of the canister

Table 17 [illegible]

Cation or Species	Concentration (mg/l)
Calcium	0.5
Copper	[illegible]
[illegible]	[illegible]
[illegible]	[illegible]
Magnesium	[illegible]
Manganese	[illegible]
Mercury	0.005
Nickel	0.05
Platinum	[illegible]
Potassium	[illegible]
Sodium	[illegible]
Titanium	0.20
Zinc	5.00

Anionic Species	
Ammonia as N	1.5
Chlorides	12.0
Chromate	0.1 (Cr^{+6} = .05)
Fluoride	1.6
Nitrate	0.04
Selenite	0.08 (Se = .05)
Sulfate	10.0

Particulate	
Silica (50 - 100 μ)	100
Bacteria	100,000/liter

Other	
Total Organics	10[illegible] (50/10)
pH (pH units)	4.0

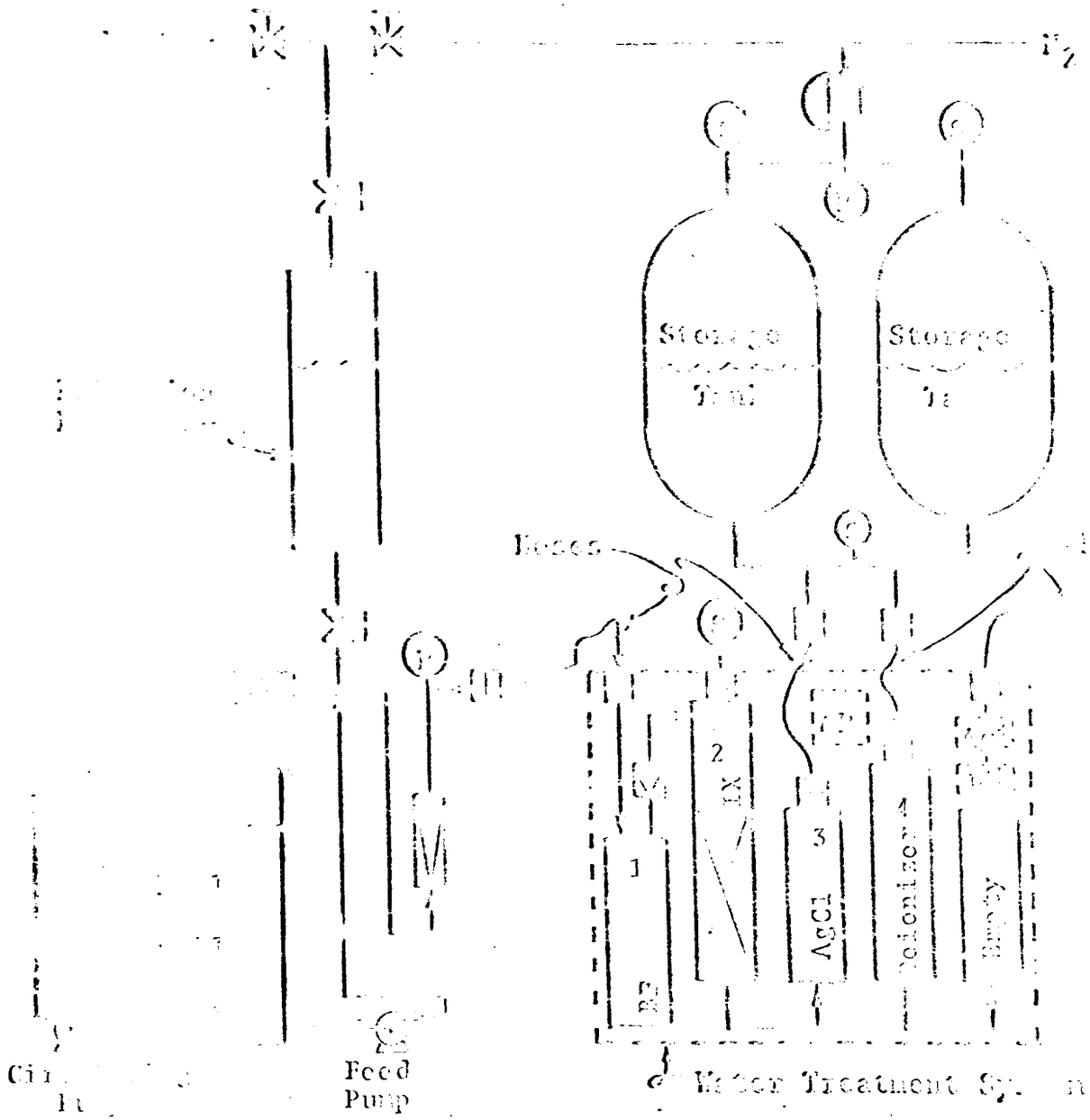


Figure 25 FLOW SCHEMATIC FOR EXTENDED TESTS WITH CHLORIDES IN SEDIMENT

The modified ... system processed two concentrations ("worst case" and "low case") of General Electric ... fuel cell water ... simulant to exhaustion - i.e., until the product water went out of potability specifications. The "low case" test was deleted because sufficient data was collected to predict breakthrough confidently and in view of [illegible] (Section 7.5) were substituted. Pseudomonas [illegible], [illegible], and Bacillus subtilis were injected into the ... points of entry - namely, the ... and the storage tanks, during the first six test days [illegible]. On the seventh test day no injection was made; day 7 was used to evaluate the effect of longer retention time on the Bacillus subtilis spores. Since the tests were performed until exhaustion of the system, the sequence was repeated on those days succeeding day 7. In the "low case" test no bacteria injections were made during week-ends because the results could be predicted. All simulant and product flow rates were the same as those used in previous tests. ... system was refurbished and resterilized for the "low case" test.

7.2.3 Extended Test No. 4 - Results and Discussion

In Extended Test No. 4, the system processed "worst case" General Electric type fuel cell water ... ambient temperatures, 294 - 297°K (70 - 75°F), during the period April 12 to April 20, 1973. Table 18 lists the daily water quality characteristics. The tabulated results show that the ion exchange resins absorbed 60% of the organics during the first five test days and thereafter virtually none. The product water pH fell below potability specifications on test day 8. The silver ion concentrations were approximately 1 ppm in the stored water and approximately 0.05 ppm in the product water.

Figures 26 and 27 show the hydraulic characteristics of the system before and after Extended Test No. 4. The data indicates no significant change in pressure drop across any of the components as a result of operating eight days at "worst case" conditions.

Table 19 lists the daily doses of bacteria injected and the plate counts on various samples. On test days 1, 3, 5, and 8 when the simulant was contaminated, the biological filter excluded bacteria from the system because no bacteria were detected in the stored water. On test days 2 and 4, when Pseudomonas aeruginosa and Type IIIa bacteria were introduced into the storage tanks, the tabulated results indicate that both the stored and product water were sterile (<1/200 ml). The silver ion [illegible] was bactericidal within the infusion of 3 x 1 x ... hours or less. [illegible]

Table 18 EXTENDED TEST No.4 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	3.9	7.9	10.2	130	11.7	26.0	<1.0	169	<0.010
	Stored 4th*	7.5	310.0	0.28	20	<1.0	<1.0	1.0	0	1.18
	Stored 21st*	7.5	300.0	0.22	30	<1.0	<1.0	1.0	10	1.20
	Product	7.5	330.0	<0.10	20	<1.0	<1.0	1.0	7	0.046
2	Simulant	3.9	7.8	10.0	140	11.7	26.0	<1.0	173	<0.010
	Stored 4th*	7.6	410.0	0.26	60	<1.0	<1.0	1.0	7	1.16
	Stored 21st*	7.6	410.0	0.22	60	<1.0	<1.0	1.0	2	1.18
	Product	7.6	420.0	<0.10	40	<1.0	<1.0	1.0	9	0.044
3	Simulant	3.9	7.8	10.6	140	11.7	26.0	<1.0	195	<0.010
	Stored 4th*	7.0	410.0	0.24	70	<1.0	<1.0	1.0	6	1.16
	Stored 21st*	7.0	410.0	0.22	70	<1.0	<1.0	1.0	0	1.16
	Product	7.1	420.0	<0.10	40	<1.0	<1.0	1.0	0	0.048
4	Simulant	3.9	7.8	10.0	140	11.7	26.0	<1.0	186	<0.010
	Stored 4th*	7.0	320.0	0.22	70	<1.0	1.0	1.4	5	1.16
	Stored 21st*	7.0	320.0	0.18	70	<1.0	1.0	1.4	0	1.18
	Product	7.1	335.0	<0.10	55	<1.0	1.0	1.4	0	0.046
5	Simulant	3.9	7.8	10.4	140	11.7	26.0	<1.0	234	<0.010
	Stored 4th*	6.8	310.0	0.20	90	2.5	<1.0	2.5	20	1.04
	Stored 21st*	6.8	310.0	0.18	90	2.5	<1.0	2.5	8	1.02
	Product	7.1	330.0	<0.10	80	<1.0	1.0	2.0	3	0.040

* Denotes Hour

Table 18 Concluded

Test Day No.	Sample Point	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
6	Simulant	3.9	7.8	10.0	140	11.7	26.0	<1.0	220	<0.010
	Stored 4th*	6.8	310.0	0.11	120	2.5	1.2	3.0	10	1.02
	Stored 21st*	6.8	310.0	0.12	120	2.5	1.2	3.0	10	1.02
	Product	6.9	350.0	<0.10	80	1.5	1.0	2.0	20	0.040
7	Simulant	3.9	7.8	10.0	140	11.7	26.0	<1.0	222	<0.010
	Stored 4th*	5.5	100.0	0.11	140	3.0	2.0	3.0	0	0.96
	Stored 21st*	5.6	110.0	0.13	140	3.0	2.0	3.0	0	0.98
	Product	6.7	110.0	<0.10	100	2.0	1.2	2.0	6	0.040
8	Simulant	3.9	7.8	10.4	140	11.7	26.0	<1.0	218	<0.010
	Stored 4th*	4.6	46.0	0.21	140	3.5	14.0	<1.0	9	0.94
	Stored 21st*	4.4	40.0	0.18	140	3.5	16.0	<1.0	14	0.92
	Product	5.7	66.0	<0.10	140	2.5	1.8	2.0	11	0.040

* Denotes Hour

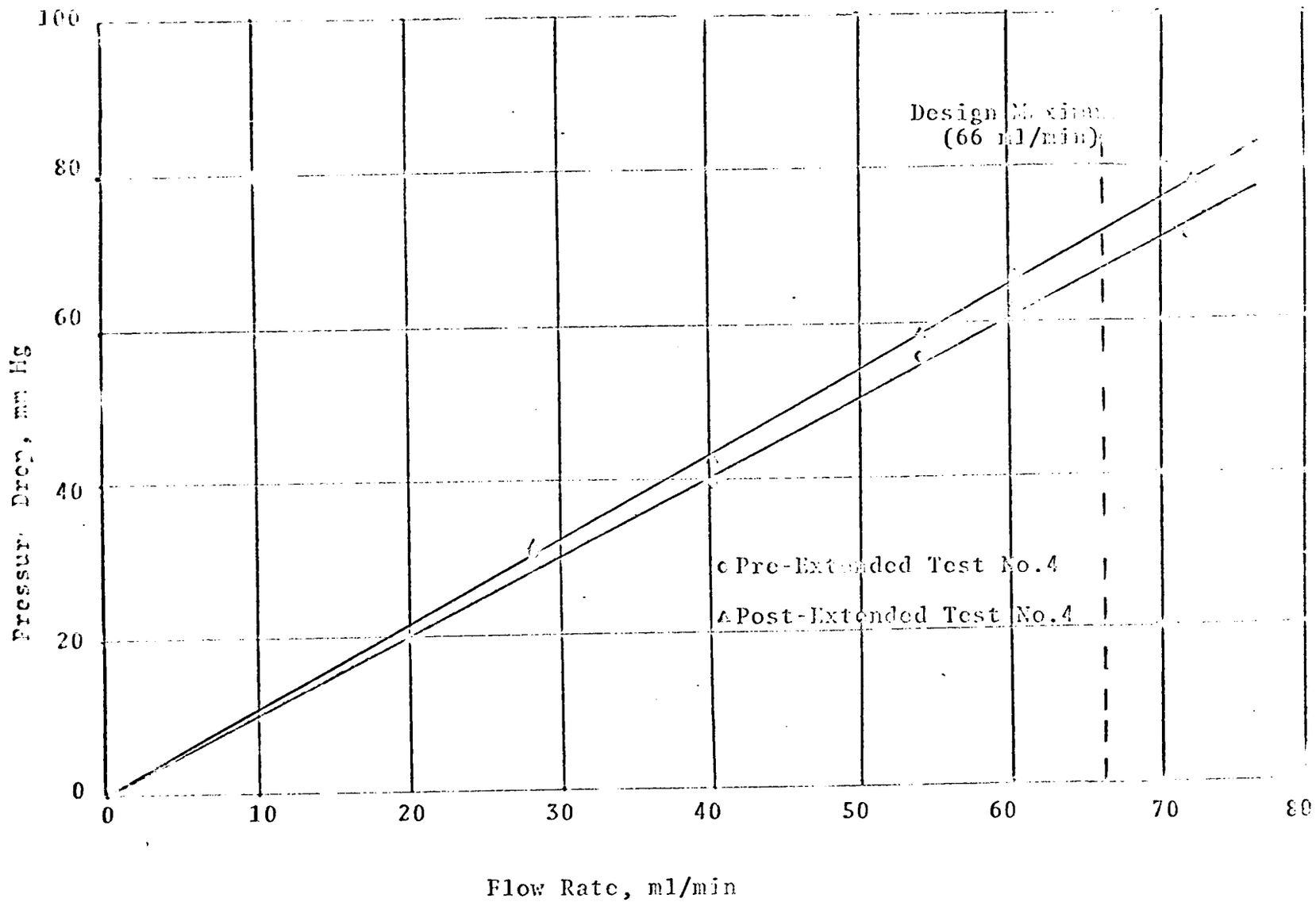


Figure 26 FLOW RESISTANCE ON INLET TO STORAGE SIDE OF PFP

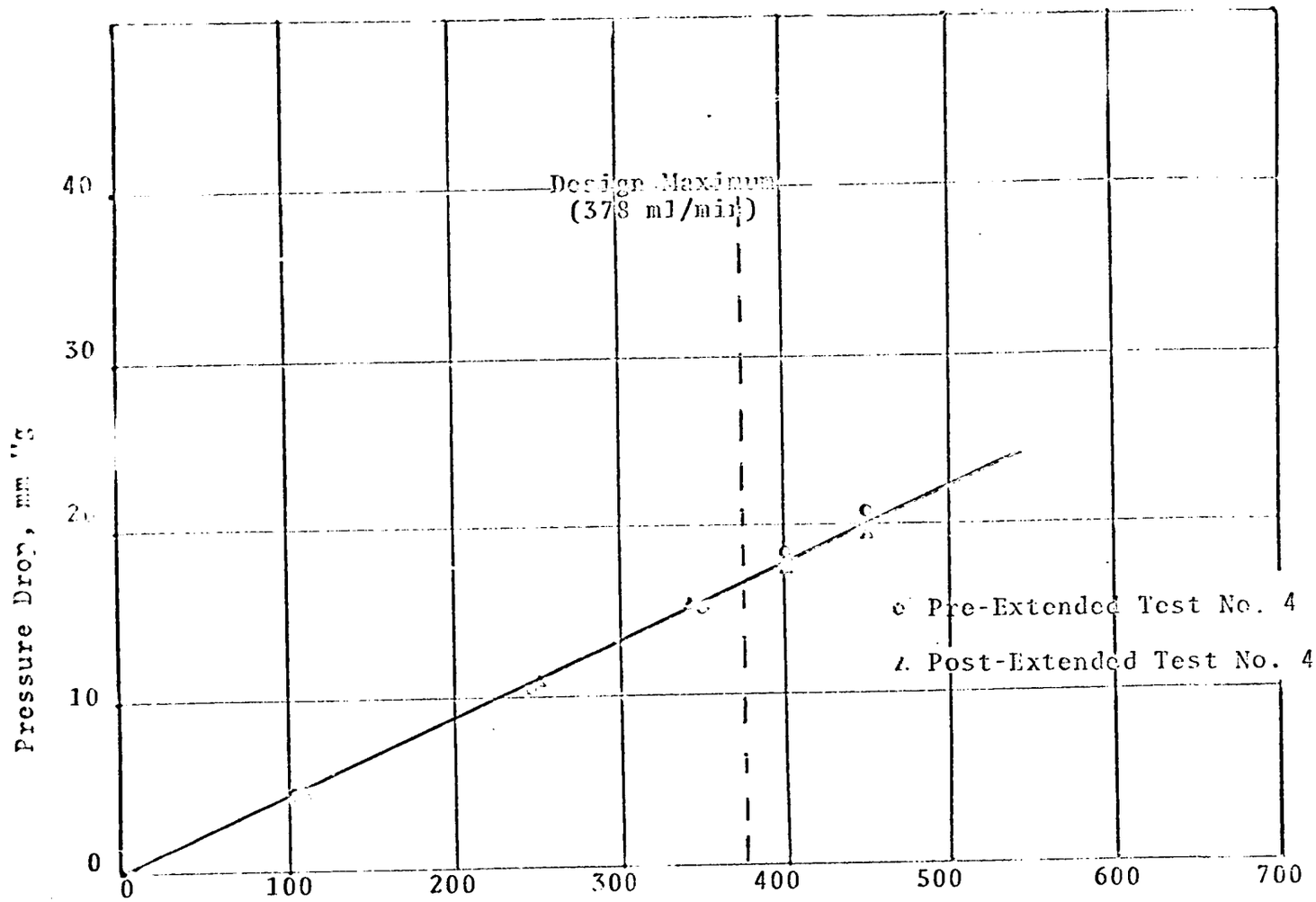


Figure 27 FLOW RESISTANCE ON STORAGE TO OUTLET SIDE OF PFP

Table 19 SUMMARY OF BACTERIOLOGIC ANALYSES FOR EXTENDED TEST No.4

Test Day	Dose(1) Injection Point	Dose(1) Number & Specie	Simulant(2)	Sample Points: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant	$3\pm1\times10^{9}$ P.a.	$3\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Storage	$3\pm1\times10^{9}$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Simulant	$3\pm1\times10^{9}$ IIIa	$3\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Storage	$3\pm1\times10^{9}$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
5	Simulant	$3\pm1\times10^{4}$ B.s.	$3\pm1\times10^{4}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
6	Storage	$3\pm1\times10^{4}$ B.s.	2/100ml*	4	<1/200ml	22	10/200ml	23	4/100ml
				21	2/100ml	23	1/100ml	24	1/100ml
7	None	------	<1/200ml	4	<1/200ml	22	<1/200ml	23	1/100ml*
				21	<1/200ml	23	<1/200ml	24	2/100ml*
8	Simulant	$3\pm1\times10^{9}$ P.a.	$3\pm1\times10^{5}$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	2/100ml*

(1) All doses injected during start-up, (1st hour).
(2) All simulant samples taken during 24th hour.
(3) Outlet valve.

* Bacillus subtilis

Bacteria in the system on test days 7 and 8 were Bacillus subtilis from the injection on day 6. The deionizer became contaminated on day 6 and the bacteria present in the cold water valve were Bacillus subtilis that were diluted and flushed out. The 0.050 ppm silver ion dose was more efficacious at elevated temperatures, 332 - 336°K (135 -145°F); the Bacillus subtilis counts at the hot water outlet valve were always lower than at the cold water outlet valve.

The bacteriological data in Table 19 indicates that the General Electric "worst case" fuel cell water simulant with 100 ppm organics (20 ppm each of toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone, and xylenol) had no deleterious effects on Pseudomonas aeruginosa and/or Type IIIa bacteria. Samples withdrawn from the simulant tank 24 hours after bacteria injections were found to be within the range anticipated (i.e., $3 \pm 1 \times 10^9$/94 liters or $3 \pm 1 \times 10^4$/ml).

It appears that the General Electric "worst case" fuel cell water simulant with 100 ppm organics was a growth media for the Bacillus subtilis. The sample withdrawn from the simulant tank on test day 5 was found to contain $3 \pm 1 \times 10^4$/ml. The sample should have only contained $3 \pm 1 \times 10^4$/94 liters or 3 ± 1/10ml. The aerobic conditions in the simulant tank apparently germinated some of the spores to the vegetative form and then proliferation occurred.

7.2.4 Extended Test No. 5 - Results and Discussion

In Extended Test No. 5, the system processed "low case" General Electric type fuel cell water simulant at ambient temperatures, 294 - 297°K (70 - 75°F), during the period April 30 to May 20, 1973. Table 20 lists the daily water quality characteristics. The tabulated results as indicated by the COD analyses show no discernible absorption of the organics by the ion exchange resins. The product water fell below potability specifications on test day 19.

The silver ion concentration was approximately 1 ppm in the stored water during the first 13 test days. Thereafter, the silver ion concentration decreased daily as the absorptive capacity of the ion exchange resin bed upstream of the AgCl canister diminished. The chloride content began to break through on test day 14 as a result of the loss in ion exchange resin capacity and the presence of chloride ions above 1 ppm suppressed the solubility of AgCl. Consequently, the silver ion content of the stored water began to decrease on test day 14 from 0.9 ppm (when the chloride ion content was 1.4 ppm) to 0.16 ppm on test day 20 (when the chloride ion content was 4.0 ppm).

Table 20 EXTENDED TEST No. 5 WATER QUALITY CHARACTERISTICS

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
1	Simulant	3.9	17.6	2.3	10	4.0	24.0	<1.0	23	<0.010
	Stored 4th*	7.6	370.0	0.14	15	<1.0	<1.0	<1.0	6	1.18
	Stored 21st*	7.6	370.0	<0.10	15	<1.0	<1.0	<1.0	8	1.18
	Product	7.8	420.0	<0.10	10	<1.0	<1.0	<1.0	4	0.060
2	Simulant	3.9	17.6	1.6	10	4.0	24.0	<1.0	21	<0.010
	Stored 4th*	7.4	360.0	0.11	10	<1.0	<1.0	<1.0	2	1.16
	Stored 21st*	7.4	360.0	<0.10	15	<1.0	<1.0	<1.0	9	1.18
	Product	7.6	610.0	<0.10	15	<1.0	<1.0	<1.0	8	0.055
3	Simulant	3.9	17.6	2.4	10	4.0	24.0	<1.0	13	<0.010
	Stored 4th*	7.3	360.0	0.11	10	<1.0	<1.0	<1.0	2	1.16
	Stored 21st*	7.3	360.0	<0.10	10	<1.0	<1.0	<1.0	1	1.16
	Product	7.6	600.0	<0.10	10	<1.0	<1.0	<1.0	1	0.055
4	Simulant	4.0	17.7	1.4	10	4.0	24.0	<1.0	30	<0.010
	Stored 4th*	7.3	340.0	<0.10	10	<1.0	<1.0	<1.0	13	1.18
	Stored 21st*	7.3	340.0	<0.10	10	<1.0	<1.0	<1.0	1	1.20
	Product	7.6	600.0	<0.10	15	<1.0	<1.0	<1.0	6	0.055
5	Simulant	4.1	18.0	1.8	10	4.0	24.0	<1.0	51	<0.010
	Stored 4th*	7.1	360.0	0.19	10	<1.0	<1.0	<1.0	22	1.10
	Stored 21st*	7.1	370.0	0.18	10	<1.0	<1.0	<1.0	20	1.10
	Product	7.6	610.0	0.11	10	<1.0	<1.0	<1.0	6	0.055

* Denotes Hour

Table 20 Continued

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
	Simulant	4.0	18.0	1.4	10	4.0	24.0	<1.0	61	<0.010
	Stored 4th*	7.0	340.0	0.16	10	<1.0	<1.0	<1.0	43	1.12
	Stored 21st*	7.1	320.0	0.10	15	<1.0	<1.0	<1.0	31	1.10
	Product	7.6	510.0	<0.10	10	<1.0	<1.0	1.0	37	0.055
7	Simulant	4.0	16.0	1.2	10	4.0	24.0	<1.0	19	<0.010
	Stored 4th*	7.0	380.0	0.16	15	<1.0	<1.0	<1.0	<1	1.16
	Stored 21st*	7.1	340.0	0.23	10	<1.0	<1.0	<1.0	9	1.20
	Product	7.5	610.0	<0.10	10	<1.0	1.0	1.0	11	0.055
8	Simulant	4.0	16.0	2.1	10	4.0	24.0	<1.0	30	<0.010
	Stored 4th*	7.0	320.0	0.14	10	<1.0	<1.0	<1.0	2	1.14
	Stored 21st*	7.0	340.0	0.10	10	<1.0	<1.0	<1.0	7	1.16
	Product	7.5	490.0	<0.10	10	<1.0	1.0	1.0	14	0.055
9	Simulant	4.0	16.0	0.98	10	4.0	22.0	<1.0	28	<0.010
	Stored 4th*	6.8	320.0	0.28	10	<1.0	<1.0	<1.0	<1	1.14
	Stored 21st*	6.8	330.0	0.12	10	<1.0	<1.0	<1.0	1	1.16
	Product	7.4	480.0	<0.10	10	<1.0	1.0	1.0	<1	0.055
10	Simulant	4.0	16.0	1.4	15	4.0	24.0	<1.0	10	<0.010
	Stored 4th*	6.8	320.0	0.12	15	<1.0	<1.0	<1.0	<1	1.14
	Stored 21st*	6.9	330.0	0.13	10	<1.0	<1.0	<1.0	7	1.12
	Product	7.4	485.0	<0.10	15	<1.0	1.0	1.0	8	0.055

* Denotes Hour

Table 20 Continued

Test Day No.	Sample Water	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag^+ (ppm)
11	Simulant	4.1	16.0	0.96	10	4.0	22.0	<1.0	1[illegible]	<0.010
	Stored 4th*	6.8	310.0	0.12	15	<1.0	1.0	<1.0	<1	1.16
	Stored 21st*	6.9	330.0	<0.10	10	<1.0	1.0	<1.0	<1	1.14
	Product	7.4	510.0	<0.10	10	<1.0	1.2	1.0	<1	0.055
12	Simulant	4.1	16.5	0.96	10	4.0	22.0	<1.0	21	<0.010
	Stored 4th*	6.8	280.0	0.14	10	<1.0	<1.0	<1.0	2	1.12
	Stored 21st*	6.9	290.0	0.12	10	<1.0	<1.0	<1.0	4	1.08
	Product	7.4	500.0	<0.10	10	<1.0	1.2	1.0	6	0.050
13	Simulant	4.1	16.0	0.89	10	4.0	22.0	<1.0	7	<0.010
	Stored 4th*	6.1	250.0	0.11	15	<1.0	<1.0	1.0	4	1.00
	Stored 21st*	6.2	270.0	0.10	10	<1.0	<1.0	1.0	<1	1.00
	Product	7.4	490.0	<0.10	15	<1.0	1.2	1.0	12	0.050
14	Simulant	4.0	16.5	1.1	10	4.0	22.0	<1.0	4	<0.010
	Stored 4th*	5.9	160.0	0.12	15	1.2	1.4	<1.0	18	0.96
	Stored 21st*	5.9	170.0	0.10	15	1.4	1.4	<1.0	6	0.90
	Product	7.1	490.0	<0.10	10	<1.0	1.4	1.0	5	0.050
15	Simulant	4.0	16.0	1.9	10	4.0	22.0	<1.0	24	<0.010
	Stored 4th*	5.3	100.0	<0.10	10	1.5	4.0	<1.0	18	0.75
	Stored 21st*	5.4	100.0	<0.10	10	1.5	4.0	<1.0	14	0.74
	Product	7.1	480.0	<0.10	10	<1.0	1.4	1.0	20	0.045

* Denotes Hour

Table 20 Concluded

Test Day No.	Sample Matter	pH	Spec. Resis. (Kohm-cm)	Turbidity (JTU's)	COD (ppm)	Cl^- (ppm)	Acidity (ppm)	Alkalinity (ppm)	TS (ppm)	Ag* (ppm)
16	Simulant	4.0	16.0	1.1	10	4.0	14.0	<1.0	30	<0.010
	Stored 4th*	4.9	72.0	<0.10	10	3.0	6.0	<1.0	25	0.66
	Stored 21st*	4.9	64.0	<0.10	10	3.0	6.0	<1.0	17	0.66
	Product	6.9	350.0	<0.10	10	1.0	1.4	1.0	20	0.015
17	Simulant	4.0	16.0	1.9	10	4.0	14.0	<1.0	52	<0.010
	Stored 4th*	4.6	51.0	0.16	10	3.0	9.0	<1.0	14	0.35
	Stored 21st*	4.6	47.0	0.14	10	3.0	9.0	<1.0	27	0.55
	Product	6.9	310.0	<0.10	10	1.0	2.0	<1.0	26	0.050
18	Simulant	4.0	16.5	1.0	15	4.0	14.0	<1.0	40	<0.010
	Stored 4th*	4.2	31.0	0.16	15	3.5	10.0	<1.0	30	0.37
	Stored 21st*	4.4	26.0	0.16	15	4.0	12.0	<1.0	40	0.30
	Product	6.5	110.0	<0.10	10	1.0	4.0	<1.0	40	0.025
19	Simulant	4.0	16.5	0.88	10	4.0	14.0	<1.0	29	<0.010
	Stored 4th*	4.1	18.5	0.12	10	3.5	12.0	<1.0	25	0.20
	Stored 21st*	4.0	16.5	0.11	10	3.5	12.0	<1.0	18	0.20
	Product	5.8	90.0	<0.10	10	1.25	6.0	<1.0	17	0.021
20	Simulant	4.0	17.0	0.80	10	4.0	14.0	<1.0	41	<0.01[illegible]
	Stored 4th*	4.0	16.5	0.12	10	4.0	14.0	<1.0	28	0.170
	Stored 21st*	4.0	16.5	0.10	10	4.0	14.0	<1.0	31	0.1[illegible]0
	Product	5.1	85.0	<0.10	10	1.4	6.0	<1.0	19	0.0[illegible]

* Duplicate Hour

The silver ion concentration was approximately 0.050 ppm in the product water during the first 13 test days. The silver ion content of the product water decreased from 0.050 ppm on day 14 to 0.0[illegible] ppm on day 20, as the silver ion content of the stored water decreased.

Figures 28 and 29 show the hydraulic characteristics of the system before and after Extended Test No. 5. The data indicates no significant change in pressure drop across any of the components as a result of operating 20 days at "low case" conditions.

Table 21 lists the daily doses of bacteria injected and the plate counts performed on various samples. The data in this table indicates that the biological results obtained during Extended Test No. 5 were similar to the results of Extended Test No. 4; they are as follows.

A. The biological filter effectively excluded bacteria.

B. A 1 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $3 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa and/or Type IIIa in 4 hours or less.

C. A 1 ppm silver ion dose at ambient temperature reduced Bacillus subtilis counts by two orders of magnitude in 24 hours.

D. A 0.050 ppm silver ion dose was more efficacious at elevated temperatures, 332 - 336°K (135 - 145°F). When breakthrough and/or contamination occured, the Bacillus subtilis counts at the hot water outlet valve were lower than at the cold water outlet valve.

E. The simulant with 10 ppm organics did not affect either Pseudomonas aeruginosa or Type IIIa bacteria. Counts after 24 hours were found to be within the range anticipated.

F. Under aerobic conditions the simulant with 10 ppm organics was synergistic to the proliferation of Bacillus subtilis.

Bacteria present in the system on test days 10 to 14 inclusive were Bacillus subtilis from the injection on day 9. The deionizer became contaminated on day 9 and the bacteria present were Bacillus subtilis that were diluted and flushed out. It appears that the system "cleansed" itself by day 15 as indicated by counts of <1/200 ml on both stored and product water.

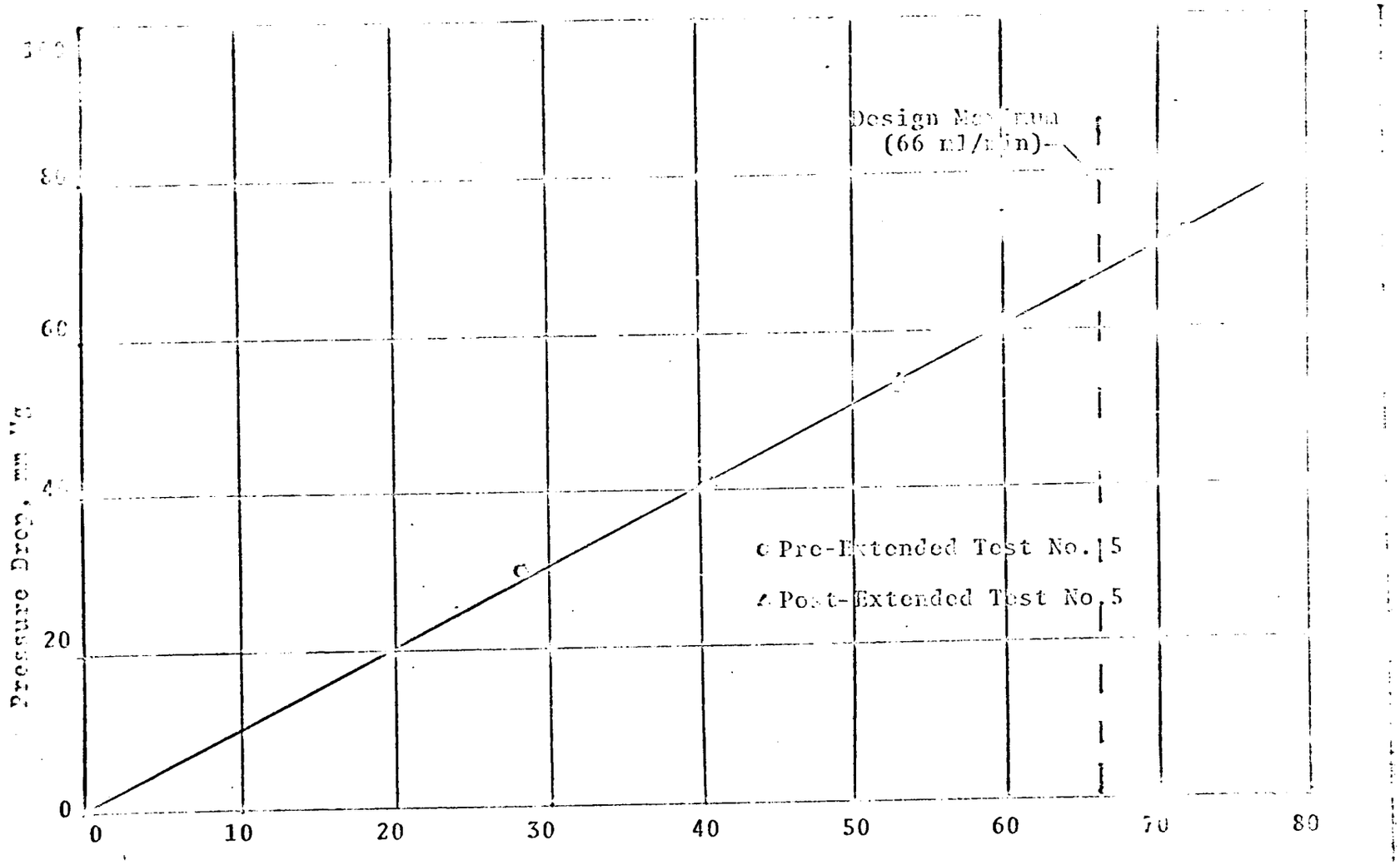


Figure 28 FLOW RESISTANCE ON INLET TO STORAGE SIDE OF PFP

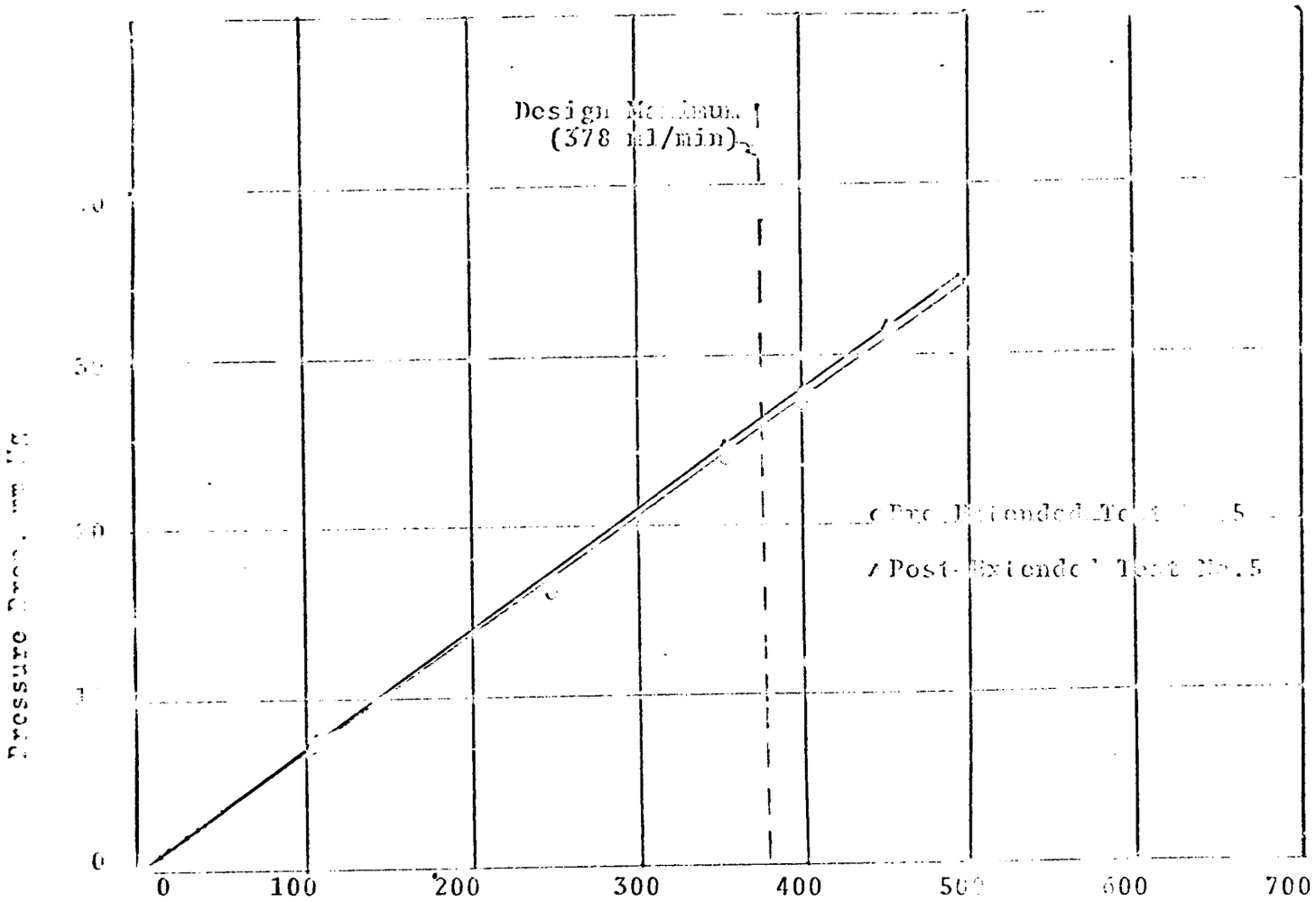


Figure 29 FLOW RESISTANCE ON STORAGE TO OUTLET SIDE OF PFP

Table 21 SUMMARY OF BACTERIOLOGIC ANALYSES FOR EXTENDED TEST 2.5

Test Point	Dose(1) Injection Point	Number & Specie	Simulant(2)	Sample Point: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V.(3) Count	Cold O.V. Hr	Cold O.V. Count
1	Simulant	$3\pm1x10^9$ P.a.	$3\pm1x10^4$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
2	Storage	$3\pm1x10^9$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
3	Simulant	$3\pm1x10^9$ IIIa	$3\pm1x10^4$ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
4	Storage	$3\pm1x10^9$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200
5	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------
6	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------
7	None	------	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
8	Simulant	$3\pm1x10^4$ B.s.	$5x10^4$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml

(1) All doses injected during start-up,(1st hour).
(2) All simulant samples taken during 24th hour.
(3) Outlet valve

Table 7.4-1 (Continued)

Run No.	Dose(1) Injection Point	Number & Specie	Simulant(2)	Sample Point: Stored Water Hr	Stored Water Count	Hot G.V. (3) Hr	Hot G.V. Count	Cold G.V. Hr	Cold G.V. Count
9	Storage	3.1×10^4 B.s.	(/100ml*	4	<1/200ml	22	1/100ml	23	<1/200ml
				21	3/100ml	23	1/100ml	24	4/100ml
10	None	------	<1/200ml	4	<1/200ml	22	3/100ml*	23	1/100ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
11	Simulant	$3 \pm 1 \times 10^9$ P.a.	$4 \pm 1 \times 10^5$/ml	4	<1/200ml	22	2/100ml*	23	3/100ml
				21	<1/200ml	23	5/100ml	24	<1/200ml
12	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------
13	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------
14	Storage	$3 \pm 1 \times 10^9$ P.a.	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	2/100ml
15	Simulant	$3 \pm 1 \times 10^9$ IIIa	$4 \pm 1 \times 10^5$/ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml
16	Storage	$3 \pm 1 \times 10^9$ IIIa	<1/200ml	4	<1/200ml	22	<1/200ml	23	<1/200ml
				21	<1/200ml	23	<1/200ml	24	<1/200ml

(1) All doses injected during start-up, (1st hour).
(2) All simulant samples taken during 24th hour.
(3) Outlet valve

* Bacillus subtilis

Table 7-4 Concluded

Test No.	Dose(1) Injection Point	Number & Species	Simulant(2)	Sample Point: Stored Water Hr	Stored Water Count	Hot O.V.(3) Hr	Hot O.V. Count	Cold O.V. Hr	Cold O.V. Count
17	Simulant	$\sim$ x10^4 B.s.	$4x10^{\prime}$/ml	4	<1/200ml	22	<1/ 0ml	23	<1/200ml
				21	<1/200ml	23	<1/ 0ml	24	<1/200ml
18	Storage	$3\pm1x10^4$ B.s.	<1/200ml	4	1/100ml	22	4/ 0ml	23	1/100ml
				21	3/100ml	23	2/ 00ml	24	8/100ml
19	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------
20	None	------	------	4	------	22	------	23	------
				21	------	23	------	24	------

(1) All doses injected during start-up,(1st hour).
(2) All simulant samples taken during 24th hour.
(3) Outlet valve

7.3 Silver Bromide Efficacy Tests

Silver bromide efficacy tests were substituted for an extended test with "mid case" General Electric fuel cell water simulant. Four tests were performed with only the AgBr column of the PFP system dosing anticipated fuel cell water simulant with silver ions. The objective was to determine the efficacy of a 0.05 ppm silver ion dose from a AgBr canister with respect to two species of bacteria, namely, Pseudomonas aeruginosa and Type IIIa.

7.3.1 Anticipated FCW Simulant Definition

The contituents along with their respective concentrations for anticipated fuel cell water simulant, based on the existing Space Shuttle potable water baseline, are listed in Table 22. Two concentrations of organics were used, 10 and 100 ppm.

7.3.2 Test Set-Up Procedure

Figure 30 shows the arrangement of components used in these tests. As indicated, the system consisted only of a AgBr canister with a partial bypass. The bypass arrangement was modified to deliver 0.05 ppm Ag^+ at a flow rate of 66 ml/min (8.7 lb/hr) from the fuel cell. The testing was performed at ambient temperatures, 294 - 297°K (70 - 75°F), as follows:

A. Anticipated fuel cell water simulant was pumped through the AgBr canister at a flow rate of 66 ml/min (8.7 lb/hr), overnight until the storage tanks were filled with 63 liters of silver bromide dosed simulant.

B. $3 \pm 1 \times 10^9$ bacteria were injected into the storage tanks (i.e., the same dosage of biological contaminants as employed in all previous testing). After mixing, the resultant concentration of microorganisms was approximately $5 \pm 1 \times 10^4$/ml.

C. Samples in 2 liter increments were drawn off at the outlet valve at the following times after bacteria injection and subjected to plate counts.

(a) 15 minutes
(b) 30 minutes
(c) 1 hour
(d) 2 hours
3 hours
4 hours
5 hours
7 hours
24 hours

Table 22 ANTICIPATED FCW SIMULANT COMPOSITION

Properties	Limits (Maximum Allowance)
a. pH	6.0-8 at 25°C (77°F)
b. Total Solids	20 ppm
c. Taste and Odor	None at Threshold (Odor No. of 3)
d. Turbidity	11 Units
e. Color, True	15 Units
f. Total Organics	10 ppm

Particulate Size Range	No. of Particles per 500 ml Fluid
a. 0-10 microns	Unlimited
b. 10-25 microns	1000
c. 25-50 microns	200
d. 50-100 microns	100
e. 100-250 microns	10

Ionic Species	Maximum Allowable Concentration
a. Aluminum	For reference only
b. Cadmium	0.01 ppm
c. Chloride	1.0 ppm
d. Chromium (Hexavalent)	0.05 ppm
e. Copper	1.0 ppm
f. Iron	0.3 ppm
g. Lead	0.05 ppm
h. Magnesium	For reference only
i. Manganese	0.05 ppm
j. Mercury	0.005 ppm
k. Nickel	0.05 ppm
l. Potassium	For reference only
m. Selenium	0.05 ppm
n. Silica	For reference only
o. Silver	0.05 ppm
p. Ammonia	0.5 ppm

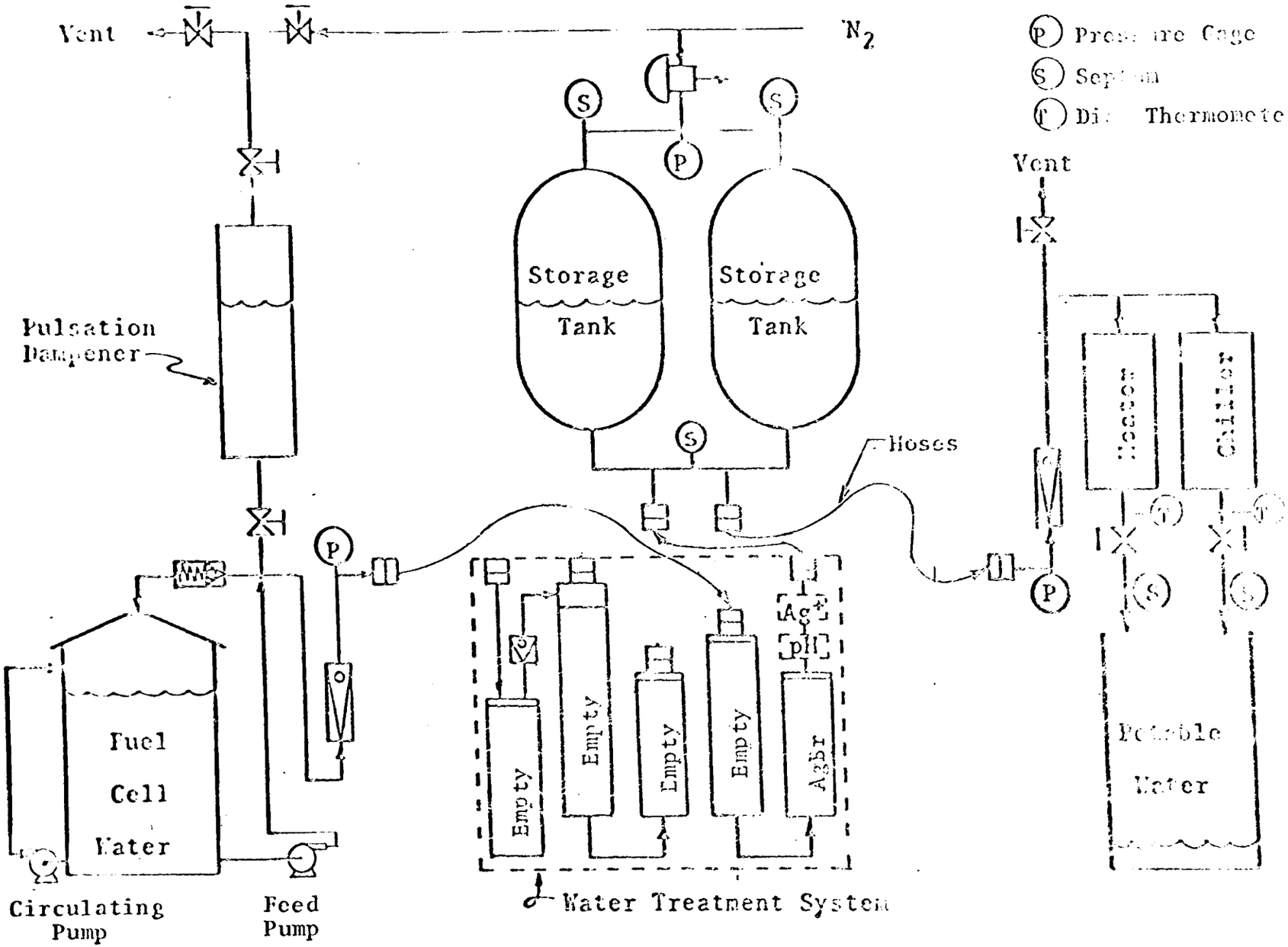


Figure 30 FLOW SCHEMATIC FOR AgBr TESTS

D. After the 24th hour, the storage tanks were emptied and the system was cleaned.

E. The same procedures and test set-up were used on the following:

(1) Anticipated FCW simulant with 10 ppm organics and Pseudomonas aeruginosa.

(2) Anticipated FCW simulant with 10 ppm organics and Type IIIa.

(3) Anticipated FCW simulant with 100 ppm organics and Pseudomonas aeruginosa.

(4) Anticipated FCW simulant with 100 ppm organics and Type IIIa.

7.3.3 AgBr Test No. 1 - Results & Discussion

During AgBr Test No. 1, anticipated fuel cell water simulant containing 10 ppm organics, dosed with approximately 0.050 ppm silver ion, was challenged with Pseudomonas aeruginosa bacteria. Table 23 summarizes the test results. The tabulated data shows that a 0.050 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa cells in 15 minutes or less.

7.3.4 AgBr Test No. 2 - Results & Discussion

During AgBr Test No. 2, anticipated fuel cell water simulant containing 10 ppm organics dosed with approximately 0.050 ppm silver ion, was challenged with Type IIIa bacteria. Table 24 summarizes the test results. The tabulated data shows that a 0.050 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Type IIIa cells in 15 minutes or less.

7.3.5 AgBr Test No. 3 - Results & Discussion

During AgBr Test No. 3, anticipated fuel cell water simulant containing 100 ppm organics, dosed with approximately 0.050 ppm silver ion, was challenged with Pseudomonas aeruginosa bacteria. Table 25 summarizes the test results. The tabulated data shows that a 0.50 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Pseudomonas aeruginosa cells in 15 minutes or less.

Table 23 AgBr TEST No.1 SUMMARY

Water Quality Characteristics

Sample	pH	Spec. Resis (Kohm-cm)	Cl^- (ppm)	COD (ppm)	Ag^+ (ppm)
Simulant	6.1	78.0	1.2	15	<0.010
15 min	6.1	79.0	1.2	15	0.050
7 hr	6.1	79.0	1.2	15	0.050
24 hr	6.1	79.0	1.2	15	0.050

Bacteriological Analyses

Injected Dose	Sample	Count
$3\pm1 \times 10^9$	Simulant	<1/200ml
Pseudomonas	15 min	<1/200ml
aeruginosa	30 min	<1/200ml
($5\pm1 \times 10^4$/ml)	1 hr	<1/200ml
	2 hr	<1/200ml
	3 hr	<1/200ml
	4 hr	<1/200ml
	6 hr	<1/200ml
	7 hr	<1/200ml
	24 hr	<1/200ml

Table 24 AgBr TEST No.2 SUMMARY

Water Quality Characteristics

Sample	pH	Spec. Resis. (Kohm-cm)	Cl^- (ppm)	COD (ppm)	Ag^+ (ppm)
Simulant	6.1	74.0	1.2	15	<0.010
15 min	6.1	74.0	1.2	15	0.050
7 hr	6.1	74.0	1.2	15	0.050
24 hr	6.1	74.0	1.2	15	0.050

Bacteriological Analyses

Injected Dose	Sample	Count
$3\pm1 \times 10^9$	Simulant	<1/200ml
Type IIIa	15 min	<1/200ml
($3\pm1 \times 10^4$/ml)	30 min	<1/200ml
	1 hr	<1/200ml
	2 hr	<1/200ml
	3 hr	<1/200ml
	4 hr	<1/200ml
	6 hr	<1/200ml
	7 hr	<1/200ml
	24 hr	<1/200ml

Table 25 AgBr TEST No.3 SUMMARY

Water Quality Characteristics

Sample	pH	Spec. Resis (Kohm-cm)	Cl^- (ppm)	COD (ppm)	Ag^+ (ppm)
Simulant	6.3	60.0	1.2	140	<0.010
15 min	6.3	60.0	1.2	130	0.050
7 hr	6.3	60.0	1.2	130	0.050
24 hr	6.3	60.0	1.2	130	0.050

Bacteriological Analyses

Injected Dose	Sample	Count
$3\pm1 \times 10^9$	Simulant	<1/200ml
Pseudomonas	15 min	<1/200ml
aeruginosa	30 min	<1/200ml
($5\pm1 \times 10^4$/ml)	1 hr	<1/200ml
	2 hr	<1/200ml
	3 hr	<1/200ml
	4 hr	<1/200ml
	6 hr	<1/200ml
	7 hr	<1/200ml
	24 hr	<1/200ml

7.3.6 AgBr Test No. 4 - Results & Discussion

During AgBr Test No. 4, anticipated fuel cell water simulant containing 100 ppm organics, dosed with approximately 0.050 ppm silver ion, was challenged with Type IIIa bacteria. Table 26 summarizes the test results. The tabulated data shows that a 0.050 ppm silver ion dose was bactericidal against the infusion of $3 \pm 1 \times 10^9$ (i.e., $5 \pm 1 \times 10^4$/ml) Type IIIa cells in 15 minutes or less.

7.4 Odor and Taste Tests

Two properties of the anticipated fuel cell water used in the AgBr tests are taste and odor. The limits or maximum allowance for these properties is none at Threshold No. of 3. Upon completion of the AgBr tests, threshold number tests were performed using the methods listed in the "Standard Method Text", 13th ed., Sec. 136, p. 248 for Odor - and Sec. 161, p. 347 for Taste.

For increased precision, a panel of five evaluators was used to make all measurements. All odor measurements were made at 333°K (140°F) and taste measurements at 313°K (104°F). From these tests, the anticipated fuel cell simulated composition with 10 ppm organics was found to have a Threshold Odor No. of 8 and a Threshold Taste No. of 10.

Determinationswere also made on samples for Extended Test No. 5, product water days 1 and 20. Again, a panel of five persons was used and the tested samples were at the 333°K (140°F) and 313°K (104°F) for odor and taste, respectively. The results were: Day 1 had a Threshold Odor No. of 6 and a Threshold Taste No. of 3, while Day 20 had a Threshold Odor of 12. A taste test was not conducted on the Day 20 sample because its acceptability to ingestion was uncertain.

Extended Test No. 5 used "low case" fuel cell water simulant containing 10 ppm organics. On the basis of the above odor and taste tests, it is concluded that none of the product waters of Extended Tests No.'s 1 to 5 inclusive, satisfied the potability criteria for odor and taste. It appears that the ion exchange resins cannot adequately sorb the organics. Furthermore, it is apparent that activated charcoals will have to be utilized if the fuel cell water contains 10 ppm organics (2 ppm each of toluene, propyl acetate, sodium lauryl sulfate, isobutyl methyl ketone and xylenol).

Table 26 AgBr TEST No.4 SUMMARY

Water Quality Characteristics

Sample	pH	Spec. Resis (Kohm-cm)	Cl^- (ppm)	COD (ppm)	Ag^+ (ppm)
Simulant	6.3	60.0	1.2	140	<0.010
15 min	6.3	60.0	1.2	130	0.050
7 hr	6.3	60.0	1.2	130	0.050
24 hr	6.3	60.0	1.2	130	0.050

Bacteriological Analyses

Injected Dose	Sample	Count
$3\pm1 \times 10^9$	Simulant	<1/200ml
Type IIIa	15 min	<1/200ml
($5\pm1 \times 10^4$/ml)	30 min	<1/200ml
	1 hr	<1/200ml
	2 hr	<1/200ml
	3 hr	<1/200ml
	4 hr	<1/200ml
	6 hr	<1/200ml
	7 hr	<1/200ml
	24 hr	<1/200ml

ABBREVIATIONS

ACF	activated charcoal filter
Ag^+	silver ion
AgBr	silver bromide
AgCl	silver chloride
APHA	American Public Health Association
APT	an arbitrary designation of a nonselective medium used by Evans and Niven for cultivation of heterofermative lactic acid bacteria
AWWA	American Water Works Association
BF	biological filter
^oC	degrees Celsius
Cl^-	chloride ion
cm	centimeter(s)
cm^2	square centimeters
cm^3	cubic centimeters
COD	chemical oxygen demand
cps	cycles per second
dB/oct	decibels per octave
^oF	degrees Fahrenheit
FCW	fuel cell water
g	grams
g^2/cps	acceleration density units
HF	hydrofluoric acid

in	inch(es)
in^2	square inches
in^3	cubic inches
IX	ion exchange
JSC	Johnson Spacecraft Center
JTU	Jackson turbidity unit
^oK	degrees Kelvin
l	liter(s)
lb	pound(s)
lb/hr	pounds/hour
meq	milliequivalent(s)
MF	membrane filter
mg	milligram(s)
ml	milliliter(s)
ml/min	milliliters per minute
mm	millimeter(s)
mm Hg	millimeters of mercury pressure
N_2	nitrogen
NASA	National Aeronautics and Space Administration
PBS	phosphate buffered saline
PFP	Preliminary Flight Prototype
pH	log of the hydrogen ion concentration
pp	pages
ppb	parts per billion

ppm	parts per million
psid	pounds per square inch differential
psig	pounds per square inch gage
Reg	regulator
SMT	simulated mission test
TOC	total organic carbon
TS	total solids
WPCF	Water Pollution Central Federation
YSI	Yellow Springs Instrument
μ	micron, micro
±	plus or minus
%	percent

SILVER ANALYSES

1.0 Breadboard Test No.1 (June 20 to June 26,1972)

1.1 Stored

Day	EC3 Lab (ppb)	Chemtric (ppb)
1	1200	950
2	980	900
3	1050	1000
4	1400	1080
5	1200	1000
6	1400	960
7	1400	920

1.2 Product

1	<50	100
2	--	100
3	--	100
4	<50	100
5	--	100
6	--	70
7	<50	70

2.0 Breadboard Test No.2 (July 12 to July 18,1972)

2.1 Stored

1	900	900
2	950	1080
3	1200	1100
4	1350	1080
5	1350	1040
6	1350	1040
7	1300	1040

2.2 Product

1	80	84
2	90	86
3	80	90
4	90	82
5	100	90
6	100	80
7	100	80

3.0 PFP Test No. 1 (Nov. 27 to Dec. 3, 1972)

3.1 Stored

EC3 Sample No.	Day	EC3 Lab (ppb)	Chemtric (ppb)
1172-62	1	1300	960
63	2	1400	1200
64	3	1100	1160
65	4	1200	1200
66	5	1200	1200
67	6	1200	1220
68	7	1100	1180

3.2 Product

1172-48	1	80	24
49	2	70	20
50	3	70	24
51	4	<50	30
52	5	50	26
53	6	80	22
54	7	80	18

4.0 PFP Test No.2 (Dec. 11,1972 to Jan 5, 1973)

4.1 Stored

173-93	1	1200	1200
94	2	900	1240
95	3	900	1180
96	4	1000	1160
97	5	1300	1160
98	6	850	1240
99	7	1000	1220
100	8	900	1160
101	9	850	1060
102	10	800	1020
103	11	900	1060
104	12	500	980
105	13	800	850
106	14	950	840
107	15	850	760
108	16	600	650
109	17	600	420
110	18	350	260

4.2 Product

EC3 Sample No.	Day	EC3 Lab (ppb)	Chemtric (ppb)
173-75	1	<50	42
76	2	<50	40
77	3	<50	40
78	4	90	42
79	5	<50	44
80	6	<50	40
81	7	<50	40
82	8	<50	42
83	9	<50	44
84	10	<50	44
85	11	<50	40
86	12	<50	38
87	13	<50	40
88	14	<50	40
89	15	<50	42
90	16	<50	42
91	17	<50	38
92	18	<50	38

5.0 PFP Extended Test No.1 (Feb 19 to Feb 26, 1973)

5.1 Stored

EC3 Sample No.	Day	EC3 Lab (ppb)	Ellington Lab (ppb)	Chemtric (ppb)
373-26	1	600;600		1180
27	2	900	1200	1160
28	3	900	1000	1160
29	4	800	1000	1180
30	5	320;300	300	1160
31	6	580;540	700	1180
32	7	600	700	1140

5.2 Product

373-19	1	130	55	55
20	2	110	50	55
21	3	110	40	52
22	4	60	--	52
23	5	<50	--	52
24	6	60	--	52
25	7	70	--	55

6.0 Extended Test No.2 (Mar 5 to Mar 13,1973)

6.1 Stored

EC3 Sample No.	Day	EC3 Lab (ppb)	Ellington Lab (ppb)	Chemtric(ppb)
373-69	1	200	--	1180
70	2	300	340	1200
71	3	150	--	1140
72	4	150	220	940
73	5	150	--	920
74	6	210	--	900
75	7	1400	1000	920
76	8	200	200	900

6.2 Product

373-61	1	<50	--	52
62	2	<50	--	52
63	3	<50	--	50
64	4	<50	--	46
65	5	<50	--	40
66	6	<50	--	40
67	7	50	--	40
68	8	100	--	40

7.0 Extended PFP Test No.3 (Mar 26 to Apr 5,1973)

Stored

473-46	1	600	--	940
50	2	700	--	980
51	3	500	--	960
52	4	800	--	940
53	5	900	--	920
54	6	650	--	940
55	7	800	--	920
56	8	800	--	900
57	9	800	--	900
58	10	900	--	900
59	11	950	--	900

7.2 Product

EC3 Sample No.	Day	EC3 Lab(ppb)	Ellington Lab (ppb)	Chemtric(ppb)
473-38	1	<50	50; 50	52
39	2	<50	--	48
40	3	<50	20	50
41	4	<50	--	48
42	5	<50	--	48
43	6	<50	--	48
44	7	<50	20; 20	50
45	8	<50	--	50
46	9	<50	--	48
47	10	<50	--	46
48	11	<50	--	46

8.0 Extended PFP Test No.4 (Apr 12 to Apr 20,1973)

8.1 Stored

573-33	1	1000	--	1200
34	2	1100	--	1180
35	3	950	--	1160
36	4	1100	--	1180
37	5	850	--	1020
38	6	1000	--	1020
39	7	900	--	980
40	8	700	--	920

8.2 Product

573-25	1	<50	<20	46
26	2	<50	20	44
27	3	<50	20	48
28	4	<50	20	46
29	5	<50	20	40
30	6	<50	20	40
31	7	<50	<20	40
32	8	<50	20	40

9.0 Extended PFP Test No.5 (Apr 30 to May 20,1973)

9.1

EC3 Sample No.	Day	Product EC3 Lab(ppb)	Ellington Lab (ppb)	Chemtric(ppb)
573-106	1	<50	30	60
107	2	<50	--	55
108	3	<50	50	55
109	4	<50	--	55
110	5	<50	50	55
111	6	<50	--	55
112	7	<50	50	55
113	8	<50	--	55
114	9	<50	40	55
115	10	<50	--	55
116	11	<50	40	55
117	12	<50	--	50
118	13	<50	30	50
119	14	<50	--	50
120	15	<50	30	45
121	16	<50	--	45
122	17	<50	<20	30
123	18	<50	--	26
124	19	<50	<20	24
125	20	<50	--	24

9.2

		Stored		
573-106	1	1600	--	1180
127	2	1400	--	1180
128	3	1600	--	1160
129	4	1500	--	1200
130	5	1600	--	1100
131	6	1400	--	1100
132	7	1400	--	1200
133	8	1400	--	1160
134	9	1300	--	1160
135	10	1300	--	1120
136	11	1200	--	1140
137	12	1200	--	1080
138	13	1100	--	1000
139	14	850	--	900
140	15	750	--	740
141	16	480	--	660
142	17	200	--	350
143	18	300	--	300
144	19	140	--	200
145	20	100	--	160

10.0 Silver Bromide (AgBr) Tests

10.1 1st Set of Samples

10.1.1 Test No.1

EC3 Sample No.	Time	EC3 Lab(ppb)	Ellington Lab (ppb)	Chemtric(ppb)
673-12	15 min	100	--	50
13	24 hr	60	--	50

10.1.2 Test No.2

673-14	15 min	320	270	260
15	24 hr	120	100	50

10.1.3 Test No.3

673-20	15 min	70	--	50
21	24 hr	50	--	50

10.1.4 Test No.4

673-22	15 min	70	40	50
23	24 hr	70	--	50

10.2 2nd Set of Samples

10.2.1 Test No.1

773-9	15 min	<50		50
10	24 hr	<50		50

10.2.2 Test No.2

773-11	15 min	<50		50
12	24 hr	<50		50

10.2.3 Test No.3

773-13	15 min	220		50;125*
14	24 hr	<50		50

10.2.4 Test No.4

773-15	15 min	90		50;50*
16	24 hr	<50		50

*Results on 2nd set of samples that were sent back to Chemtric.

APPENDIX C

RANDOM VIBRATION TEST REPORTS

BY

INLAND TESTING LABORATORIES, INC.

TEST REPORT NO. 1392-1

DATE July 17, 1972

REPORT OF TEST ON

ONE (1) SET OF
WATER SYSTEM CANISTERS

FOR

CHEMTRIC, INC.

INLAND TESTING LABORATORIES, INC.
7845 Nagle Avenue
Morton Grove, Illinois 60053

TESTING

	PREPARED	CHECKED	APPROVED
BY	R. Tarosky	B. Loveless	B. Loveless
SIGNED		B Loveless	B Loveless

DATE July 17, 1972

PURPOSE OF TEST:

To determine the ability of the test specimens to withstand the applied Random Vibration specified.

MANUFACTURER:

Chemtric, Inc.,
Under Contract NAS-12792

MANUFACTURER'S TYPE OR MODEL NO.:

One (1) Set of Water System Canisters

DRAWING, SPECIFICATION OR EXHIBIT:

PO 01874

QUANTITY OF ITEMS TESTED:

One (1) Set

SECURITY CLASSIFICATION OF ITEMS:

Unclassified

DATE TEST COMPLETED:

July 11, 1972

TEST CONDUCTED BY: INLAND TESTING LABORATORIES, INC.

DISPOSITION OF SPECIMENS:

Returned to Chemtric, Inc.

ABSTRACT:

None

TESTING

REPORT NO. 1392-1

DATE July 17, 1972

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST

Requirements:

The test specimens shall satisfactorily withstand the applied vibration without exhibiting evidence of physical damage.

Test Procedure:

The test specimens were secured to a fixture which, in turn, was rigidly attached to the moving element of the vibration machine.

The specimens were then subjected to 2.5 minutes of random vibration in each of three (3) mutually perpendicular axes. The bandwidth was limited to between 20 and 2000 Hz. with the spectral density as follows:

Frequency Range (Hz.)	Test Spectrum
20 to 80	+3 dB/oct
80 to 180	0.06 g^2/cps
180 to 200	+12 dB/oct
200 to 400	0.1 g^2/cps
400 to 450	-12 dB/oct
450 to 2000	0.06 g^2/cps

Overall G rms = 11.1

Description of Test Apparatus:

Vibration Machine, MB, Model C50, S/N 127
Amplifier, MB, Model T666
Control Console, MB, Model T288, (Analyzer have (80) 25 Hz. bandwidth filters).
Accelerometer, Endevco, Model 2213, S/N 160

TESTING

REPORT NO. 1392-1

DATE July 17, 1972

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST (Cont'd)

Test Results:

Visual examination of the test specimens, limited to external surfaces, revealed no evidence of physical damage.

The specimens were then returned to Chemtric, Inc. for further examination and final determination of results.

TESTING

TEST REPORT NO. 3412-2

DATE December 14, 1972

REPORT OF TEST ON

ONE (1) CANISTER ASSEMBLY

FOR

CHEMTRIC, INC.

INLAND TESTING LABORATORIES, INC.

7845 Nagle Avenue

Morton Grove, Illinois 60053

TESTING

	PREPARED	CHECKED	APPROVED
BY	R. Tarosky	B. Loveless	B. Loveless
SIGNED		B Lovel	B Lovel

DATE December 14, 1972

PURPOSE OF TEST:

To determine the ability of the test specimens to withstand the applied Random Vibration specified.

MANUFACTURER:

Chemtric, Inc.,
Under Contract NAS9-12792

MANUFACTURER'S TYPE OR MODEL NO.:

One (1) Canister Assembly

DRAWING, SPECIFICATION OR EXHIBIT:

P. O. 01994

QUANTITY OF ITEMS TESTED:

One (1)

SECURITY CLASSIFICATION OF ITEMS:

Unclassified

DATE TEST COMPLETED:

December 8, 1972

TEST CONDUCTED BY: INLAND TESTING LABORATORIES, INC.

DISPOSITION OF SPECIMENS:

Returned to Chemtric, Inc.

ABSTRACT:

None

TESTING

REPORT NO. 3412-2

DATE December 14, 1972

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST

Requirements:

The test specimen shall satisfactorily withstand the applied vibration without exhibiting evidence of physical damage.

Test Procedure:

The test specimen was secured to a fixture which, in turn, was rigidly attached to the moving element of the vibration machine.

The specimen was then subjected to 2.5 minutes of random vibration in each of three (3) mutually perpendicular axes. The bandwidth was limited to between 20 and 2000 Hz. with the spectral density as follows:

Frequency Range (Hz.)	Test Spectrum
20 to 80	+ 3 dB/oct
80 to 180	0.06 g^2/cps
180 to 200	+12 dB/oct
200 to 400	0.1 g^2/cps
400 to 450	-12 dB/oct
450 to 2000	0.06 g^2/cps

Overall G rms = 11.1

Description of Test Apparatus:

Vibration Machine, MB, Model C50, S/N 127
Amplifier, MB, Model T666
Control Console, MB, Model T288,
(Analyzer have (80) 25 Hz. bandwidth filters).
Accelerometer, Endevco, Model 2213, S/N 160

TESTING

REPORT NO. 3412-2

DATE December 14, 1972

DESCRIPTION OF TEST:

RANDOM VIBRATION TEST (Cont'd)

Test Results:

Visual examination of the test specimen, limited to external surfaces, revealed no evidence of physical damage.

The specimen was then returned to Chemtric, Inc. for further examination and final determination of results.