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EVALUATION OF A MULTIFILTRATION WATER RECLAMATION SUBSYSTEM TO RECLAIM DOMESTIC CLOTHES WASH WATER

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EVALUATION OF A MULTIFILTRATION WATER RECLAMATION SUBSYSTEM TO RECLAIM DOMESTIC CLOTHES WASH WATER

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SUMMARY

An evaluation has been performed of a multifiltration water reclamation subsystem to determine its capability to recover water from domestic clothes wash water. A total of 32.89 kg (72.5 lb) of clothes were washed during eight wash cycles which used 0.635 kg (1.4 lb) of detergent, 549 liters (145 gallons) of hot water and 507 liters (133.9 gallons) of cold water. Water recovered at a weighted average process rate of 14.42 liters per hour (3.81 gallons per hour) met the majority of the 23 requirements established for potable water by the U.S. Public Health Service. Average power consumed during this evaluation was approximately 18.8 watt-hours per liter (71 watt-hours per gallon) of water recovered. Filter replacement, which was required primarily for the control of micro-organisms in the recovered water averaged 4.86 filters per 379 liters (100 gallons) of wash water processed. The subsystem removed approximately 98 percent and virtually 100 percent of the phosphates and surfactants, respectively, from the wash water.

INTRODUCTION

During the past decade, water reclamation technology has been developed to provide waste water recycling on manned spacecraft for long-term missions. Since this technology provided prototype subsystems with low process capacities for recycling the waste water provided by the crew, it was desired to examine one of these concepts for possible application to domestic households. It is estimated that water recycling in the average size household (ref. 1) could reduce the daily demand for potable water by 75 percent (ref. 2). The application of this technology is particularly attractive at the present time due to the increase in water demand and the resulting pollution imposed by a rapid increase in population.

In order to provide basic data to determine the feasibility of a low process capacity concept to reclaim domestic waste, a multifiltration subsystem was tested at the Langley Research Center to determine its capability to reclaim water from domestic clothes wash water. This report presents the data obtained from the test program in which three baseline tests and eight clothes wash tests were performed over a range of operating conditions. These data include chemical, physical, and microbiological analyses of both the waste and recovered waters. Also included is a comparison of the recovered water quality with the U.S. Public Health Standards given in reference 3.

SUBSYSTEM DESCRIPTION

A schematic drawing of the multifiltration subsystem used in this investigation is shown in figure 1. The subsystem consisted of the six filters shown in figure 2, and associated tanks, plumbing, pumps, and valves to process the wash water. A commercial washing machine was used to wash the clothes. The filters were arranged in the order shown to (1) remove suspended solids to protect the subsequent filters from surface fouling and plugging, (2) remove organic materials on which micro-organisms depend for nutrients, (3) remove inorganic materials which are considered to be prime pollutants in lakes and rivers, and (4) remove micro-organisms. These commercial filters were designed for applications where high purity water is desired. The filters were chosen for this evaluation because they were readily available and the advertised contaminant removal rate was sufficient to recover the daily clothes wash water provided by an average size family. A description of each filter is given below:

Filter A: This filter was used to remove suspended particles from the wash water. The filter contained a fiber-glass/asbestos medium held between layers of cellulose paper arranged to give a filtration surface area of 1.02 m^2 (11 ft^2). The medium was supported by inner and outer perforated sleeves of polypropylene with urethane end caps sealed in place. Fluid flow was from outside to inside the cartridge through a matrix which had high particulate removal capability. Nominal (depth filter) particle size rating was 0.50 μm. Filter weight was 0.481 kg (1.06 lb).

Filter B: This filter was used to remove organics, free chlorine, chloramines, phosphate complexes, and turbidity from the wash water. The filter contained 1.81 kg (4.0 lb) of adsorbing material.

Filter C: This filter contained 1.81 kg (4.0 lb) of mixed ion exchange resin and was used to remove metallic ions.

Filter D: This filter contained 1.81 kg (4.0 lb) of mixed ion exchange resin to remove carbon dioxide and ionized minerals including silica.

Filter E: This filter contained 1.81 kg (4.0 lb) of ion exchange resin to remove weakly ionized organic compounds which included suspended and colloidal particles greater than 0.1 μm.

Filter F: This filter was used to remove micro-organisms from the wash water. The filter contained microporous filter material held between two sheets of polypropylene mesh. The matrix was applied around a plastic core and protected by an outer polypropylene support. The core and support were sealed in place with polyurethane end caps. Nominal (depth filter) particle size rating was 0.22 μm and filtration surface area was 0.085 m^2 (0.91 ft^2). The filter weighed 0.54 kg (1.19 lb).

TEST SETUP AND INSTRUMENTATION

A schematic drawing of the test setup is shown in figure 1. The clothes were washed in a commercial washing machine which was connected to the local municipal water supply. Hot water was supplied by a 227-liter (60 gallon) 2000-watt hot water heater. Two iron-constantan thermocouples were used to determine the temperatures of both the hot and cold water at the input to the washing machine. The outputs from the thermocouples were monitored continuously on a strip chart recorder. Hot and cold water quantities were recorded with two integrating flow meters installed in the input water lines to the washing machine. The meters were manually recorded before and after each wash cycle. Waste water from the washing machine was collected in a 227-liter (60 gallon) tank. The waste water was transferred through the filter beds with a 186.5-watt (0.25-horsepower) centrifugal pump which operated on 110-volt alternating current. A bypass loop was installed around the pump so that the waste water pressure could be controlled in the filter beds. Flow rates were obtained by directing the flow of water through sample port 4 for a specific time interval. Two dial pressure gages were installed across the combined filter beds to determine change in pressure during a process cycle. The five sample ports, installed as shown in figure 1, were the locations used for obtaining both chemical and microbial samples for subsequent analyses to determine water quality.

TEST METHOD

The initial two baseline tests were performed without clothes or detergent. Municipal tap water was supplied to the washing machine as it was operated through normal wash cycles. The water accumulated during each washing cycle was processed through the multifiltration subsystem. The third baseline test was identical to the initial two baseline tests except that detergent was added to the tap water. The method of performing these tests was similar to that for clothes washing tests 1 to 8 which are described in the following paragraph.

Soiled clothes were weighed and placed in the washing machine. Detergent in the amount of 0.0934 kg (0.206 lb) was added to the clothes. The clothes were then automatically cleansed through a wash, rinse, and spin cycle. The entire cycle took approximately 45 minutes. At the completion of washing, the processing pump was manually initiated and the pump bypass valve adjusted to give a pressure drop across the filters of 138 kN/m^2 (20 psi) so as not to exceed the maximum design pressure of filters B to E. This pressure drop corresponded to an initial waste water flow rate through the filters of approximately 22.7 liters per hour (6.0 gallons per hour).

In order to provide a reference from which to determine degradation in process rate, the bypass valve was manually adjusted during the process cycle to maintain the stated pressure drop across the filters. When the flow rate degraded to approximately 7.57 liters per hour (2.0 gallons per hour), the expended particulate filter (A or F) was replaced to allow restoration of the original flow rate. Filter C was replaced when the dye in the resin indicated that the capacity of the filter to remove metallic ions was depleted. Quantity of waste water recovered for each test (with the exception of test 8) was that quantity that could be processed during an 8-hour work day. Test 8 was performed over two consecutive work days. The remaining unprocessed waste water was pumped into a drain at the conclusion of each test.

Subsystem performance data were taken every hour. Samples of the tap, waste, and recovered water were taken for analysis during each test to determine the capability of the multifiltration unit to remove both chemical and microbial contaminants from the waste water.

RESULTS AND DISCUSSION

Table I gives a summary of the waste water processed and filters expended, and table II gives a summary of the chemical and physical properties of the waste and recovered waters. Data shown in table II for the baseline tests with tap water are averaged values of the quantities given in appendix A. These tests were performed without clothes or detergent and used approximately the same amount of tap water. Data for the baseline test using tap water and detergent are the same as those given in appendix A since only one test was performed with detergent added to the tap water. Clothes wash tests 1 to 8 show averaged values of the data given in appendix B for ports 1 and 2 since approximately the same quantities of water were used to wash the clothes for these tests. The values given for port 5 are weighted (by volume) contaminant values obtained from appendix B to compensate for the varying quantities of water recovered for each test. The chemical contaminants and physical properties were obtained by standard methods of analysis as described in reference 4. A summary list of these techniques along with the lower detection limits achievable in the Langley water analysis laboratory are given in table III. Table IV shows micro-organism counts per milliliter for each sample port location. These values were obtained by averaging the data for all the tests for each sample port given in appendix C.

Waste Water Collection and Quality

Waste water was obtained by washing soiled clothes in a commercial washing machine. The clothes were a mixture of garments obtained from the homes of various Langley Research Center personnel. Both white and colored clothes as well as bed clothes were washed during this investigation. Clothes wash loads ranged from 2.49 to 4.88 kg (5.50 to 10.75 lb). (See table I.) Water quantity used to wash the clothes averaged 132.1 liters (34.9 gallons) per wash load of which 68.6 liters (18.1 gallons) was hot water. Hot water and cold water temperatures measured at the input to the washing machine shown in figure 1 were 60° C (140° F) and 4.4° C (40° F), respectively.

A biodegradable detergent was used for this investigation. The detergent, which was formulated for use over a range of wash water temperature, contained 12.3 percent phosphates by weight. Detergent in the amount of 0.0771 kg (0.170 lb) was used for each wash load.

The properties of the waste water are given in table II. (See data for port 2, tests 1 to 8.) Significant increases from the original tap water for all the cationic, anionic, organic, and physical properties with the exception of urea, odor, and fluoride were noted. In addition, no significant increases in the metals were noted with the exception of zinc. The increases are attributed to the ingredients in the detergent and the contaminants washed from the clothes.

Waste Water Process Rates

Waste water process rates ranged from 8.6 to 22.9 liters per hour (2.26 to 6.06 gallons per hour) for a constant pressure drop across the filters of 138 kN/m^2 (20 psi). Degradation in process rate occurred when the particulate filters began to plug; this caused an increase in pressure drop across the filter bed. Relief of the pressure increase, and consequently a reduction in process rate, was accomplished by adjusting the pump bypass valve to allow less fluid to flow through the filters. An average flow of less than 18.9 liters per hour (5 gallons per hour) was desired through the filters to correspond to their recommended contaminant removal rating.

The average process rate of effluent from the eight wash loads of clothes was 14.42 liters per hour (3.81 gallons per hour). (See table I, tests 1 to 8.) The water recovery efficiency of the subsystem, defined as the volume ratio of the water recovered to the wash water actually processed, was virtually 100 percent.

Water Quality

In the absence of standards for water reuse other than drinking water, the requirements for potable water given in reference 1 were used as a guide to determine subsystem performance during this investigation. The water was analyzed for 22 out of 23 of these requirements. The carbon chloroform extract analysis for determining concentrations of grease in the water was not performed due to the presence of detergent in the waste water. The detergent emulsified the chloroform; thus, the analysis was negated. The capability of the subsystem to recover water with less than those levels shown in table II for arsenic, selenium, and phenols could not be determined during this investigation. The minimum levels given for these contaminants are lower than the detectable limits that can be measured with existing Langley Research Center laboratory equipment. In addition, the water was analyzed for nine other parameters which were selected to give additional subsystem performance information. These were ammonia, conductivity, magnesium, nickel, pH, phosphates, total organic carbon, and urea.

The results indicate that the use of the multifiltration subsystem described in this report is feasible to recover water that meets the majority of the requirements given by the U.S. Public Health Service. The capability of the subsystem to remove most of the metals from the wash water was inconclusive because of the low levels of these contaminants present in the wash water. However, it appears that the subsystem increased the quantity of both copper and lead in the processed water. (See test 6 in table II(a).) The increase in copper is thought to be caused by detergent contamination and corrosion of the copper transport pipe between the filter bed and the storage tank. An explanation for the increase in lead is not apparent. In addition, the subsystem removed approximately 98 percent of the phosphates from the wash water. Even though the U.S. Public Health Service does not give a limit for phosphates, it is one of the primary pollutants found in sewage. Surfactant removal from the wash water as indicated by the methylene blue active substance values shown in table II was virtually 100 percent.

Filter Expendables

Table I shows the quantity of filters expended during this investigation. Of this total, two were metallic ion removal filters (filter C) and eight were particulate removal filters (filters A and F). The average filter replacement rate, therefore, was 4.86 filters per 379 liters (100 gallons) of wash water processed.

The majority of the eight particulate filters replaced were of the type used to remove micro-organisms from the wash water. These expendables could possibly be eliminated if other techniques are used for micro-organism control.

Micro-Organism Control

Table IV shows averaged micro-organisms per milliliter for the water analyzed from each sample port during this evaluation. These values were obtained by averaging the micro-organism counts given for each sample port in appendix C for all the tests.

Micro-organisms were controlled with a depth filter rated to remove particles greater than 0.22 μm in size. The effectiveness of the filter to remove micro-organisms from the processed water is shown in table IV (port 4). The filter aided in reducing the micro-organism count by an average of 5 orders of magnitude in the recovered water. Specific analysis for coliforms was not performed during this investigation. However, the subsystem did produce sterile water during the majority of the tests, which in effect demonstrated the feasibility of the technique to meet the coliform requirements given in reference 1.

Power Requirements

The power required to process the wash water was 250 watts. This power was required to operate the centrifugal pump to transport the wash water through the filter bed. The power required to heat the wash water and operate the washing machine was not charged to processing the waste water. Average power consumed to recover the clothes wash water (tests 1 to 8) was approximately 17.4 watt-hours per liter (66 watt-hours per gallon) of water recovered. This requirement can be reduced by using a pump specifically for the process rate and pressure drop across the filter bed. The pump used for this investigation had more pumping capacity than was required for the desired flow rate.

CONCLUDING REMARKS

An evaluation of a multifiltration water reclamation technique was conducted to determine its capability to reclaim water from domestic clothes wash water. The subsystem demonstrated the feasibility to produce water that meets the majority of the chemical and physical requirements for potable water established by the U.S. Public Health Service. In addition, the feasibility of the technique to remove micro-organisms from the recovered water was demonstrated through producing sterile water for the majority of the clothes wash tests. Power consumed for a weighted average process rate of 14.42 liters per hour (3.81 gallons per hour) was 18.8 watt-hours per liter (71 watt-hours per gallon) of wash water recovered. The subsystem removed approximately 98 percent and virtually 100 percent of the phosphates and surfactants, respectively, from the wash water. These contaminants are considered to be major pollutants in domestic sewage.

Filter expendables for this investigation averaged 4.86 filters per 379 liters (100 gallons) of clothes wash water processed. The majority of these expendables were required for micro-organisms control and the removal of particulate material from the clothes wash water.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., April 3, 1973.

APPENDIX A

CHEMICAL AND PHYSICAL WATER ANALYSIS FOR BASELINE TESTS

Data included in this appendix were obtained from the chemical and physical water analysis for the three baseline tests. Data are presented which show the condition of the water before and after processing. The analysis includes 22 of the 23 contaminants listed in reference 1 for potable water. In addition, data are included for nine other parameters which were selected to give additional subsystem performance information.

Metals Analysis

The data from the metals analysis for the baseline tests are given in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Baseline test		
				Tap water	Tap water	Tap water and detergent
Arsenic	ppm	0.05	1	[b]<0.10	[b]<0.10	[b]<0.10
			2	[b]<.10	[b]<.10	[b]<.10
			5	[b]<.10	[b]<.10	[b]<.10
Barium	ppm	1.00	1	<1.00	<1.00	<1.00
			2	<1.00	<1.00	<1.00
			5	<1.00	<1.00	<1.00
Cadmium	ppm	0.01	1	0.02	<0.005	<0.005
			2	<.01	<.005	<.02
			5	<.005	<.005	<.005
Chromium	ppm	0.05	1	<0.01	<0.01	<0.01
			2	.01	<.01	<.01
			5	<.01	<.01	<.01
Copper	ppm	[c]1	1	0.2	0.1	0.1
			2	<.1	<.1	.5
			5	.1	<.1	.5
Iron	ppm	[c]0.30	1	0.60	0.20	0.60
			2	<.02	.20	.60
			5	<.02	<.20	<.20
Lead	ppm	0.05	1	<0.05	<0.05	<0.05
			2	<.05	<.05	<.10
			5	<.05	<.05	<.05
Magnesium	ppm	(d)	1	3.30	3.30	3.70
			2	2.80	3.30	3.80
			5	.43	.33	.39
Manganese	ppm	[c]0.50	1	0.03	<0.01	0.01
			2	.03	<.01	.03
			5	<.01	<.01	<.01
Nickel	ppm	(d)	1	[b]<0.20	[b]<0.20	[b]<0.20
			2	[b]<.20	[b]<.20	[b]<.20
			5	[b]<.20	[b]<.20	[b]<.20
Selenium	ppm	0.01	1	<0.05	<0.05	<0.05
			2	<.05	<.05	<.05
			5	<.05	<.05	<.05
Silver	ppm	0.05	1	<0.10	<0.10	<0.10
			2	<.10	<.10	<.10
			5	<.10	<.10	<.10
Zinc	ppm	5.00	1	<0.10	<0.05	0.10
			2	<.05	<.05	<.05
			5	<.05	<.05	<.05

[a] See figure 1 for sample port location.
[b] Minimum detectable limit.
[c] Values are not mandatory requirements.
[d] No U.S. Public Health Standard.

Cation and Anion Analysis

The data from the cation and anion analysis for the baseline tests are given in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Baseline test: Tap water	Baseline test: Tap water	Baseline test: Tap water and detergent
Cations						
Ammonia	ppm	(b)	1	0.20	0.60	<0.20
			2	<.20	<.20	.60
			5	<.20	<.20	<.20
Calcium	ppm	(b)	1	26.0	26.0	26.0
			2	26.0	26.0	26.0
			5	1.5	1.0	1.5
Anions						
Chloride	ppm	[c] 250	1	25.0	26.0	26.0
			2	35.0	2.0	40.0
			5	<5.0	<5.0	<5.0
Cyanide	ppm	0.01	1	<0.02	<0.02	0.02
			2	<.02	<.02	<.02
			5	<.02	<.02	<.02
Fluoride	ppm	1.70	1	1.1	1.1	1.1
			2	1.1	1.2	1.2
			5	<.1	<.1	<.1
Nitrates and nitrites	ppm	[c] 45.0	1	<0.50	<0.50	<0.50
			2	<.50	<.50	<.50
			5	<.50	<.50	<.50
Phosphate	ppm	(b)	1	1.0	1.7	17.5
			2	1.1	.7	550.0
			5	.7	.4	1.5
Sulfate	ppm	[c] 250	1	30	30	25
			2	<5	<5	400
			5	<5	<5	<5

[a] See figure 1 for sample port location.
[b] No U.S. Public Health Standard.
[c] Values are not mandatory requirements.

Organic and Physical Analysis

The data from the organic and physical analysis for the baseline tests are presented in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Baseline test		
				Tap water	Tap water	Tap water and detergent
Organic						
Methylene blue active substances	ppm	0.50	1	0.02	0.2	0.06
			2	.02	<.01	192
			5	<.02	<.01	.02
Carbon chloroform extract	ppm	0.20	1	(b)	(b)	(b)
			2	(b)	(b)	(b)
			5	(b)	(b)	(b)
Phenols	ppm	0.001	1	<0.05	<0.05	<0.05
			2	<.05	<.05	<.05
			5	<.05	<.05	5.90
Total organic carbon	ppm	(c)	1	15	15	8
			2	15	17	180
			5	<5	<5	20
Urea	ppm	(c)	1	<50	<50	<50
			2	<50	<50	<50
			5	<50	<50	<50
Physical properties						
Color	$PtCl_6$ equiv. units	15	1	20	5	15
			2	5	5	>100
			5	<5	<5	<5
Conductivity	Micromhos per centimeter	(c)	1	200	205	200
			2	205	200	1200
			5	9	4	9
Odor	Threshold number	3.0	1	>3	<3	>3
			2	<3	<3	>3
			5	<3	>3	<3
pH	pH	(c)	1	7.3	7.4	7.5
			2	7.4	7.5	9.5
			5	7.0	7.4	5.7
Total solids	ppm	500	1	200	200	<100
			2	200	400	1300
			5	<100	200	<100
Turbidity	ppm SiO_2 equiv.	5.0	1	8.4	5.8	3.2
			2	5.8	3.9	8.5
			5	1.4	1.2	1.0

[a] See figure 1 for sample port location.
[b] Analysis not performed.
[c] No U.S. Public Health Standard.

APPENDIX B

CHEMICAL AND PHYSICAL ANALYSIS FOR CLOTHES WASH TESTS

Data included in this appendix were obtained from the chemical and physical water analysis for the eight clothes wash tests. Data are presented which show the condition of the water before and after processing. The analysis includes 22 of the 23 contaminants listed in reference 1 for potable water. In addition, data are included for nine other parameters which were selected to give additional subsystem performance information.

Metals Analysis

The data from the metals analysis for clothes wash test 6 are given in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Clothes wash test 6
Arsenic	ppm	0.05	1	[b]<0.10
			2	[b]<.10
			5	[b]<.10
Barium	ppm	1	1	<1
			2	<1
			5	<1
Cadmium	ppm	0.01	1	<0.01
			2	<.01
			5	<.01
Chromium	ppm	0.05	1	<0.05
			2	<.05
			5	<.05
Copper	ppm	[c]1	1	1
			2	.6
			5	4.0
Iron	ppm	0.30	1	1.00
			2	1.00
			5	1.00
Lead	ppm	0.05	1	<0.05
			2	<.05
			5	.15
Magnesium	ppm	(d)	1	6.50
			2	6.80
			5	.99
Manganese	ppm	0.50	1	<0.20
			2	<.10
			5	<.05
Nickel	ppm	(d)	1	<0.20
			2	<.20
			5	<.20
Selenium	ppm	0.01	1	[d]<0.10
			2	<.10
			5	<.10
Silver	ppm	0.05	1	<0.05
			2	<.01
			5	<.01
Zinc	ppm	5.00	1	0.29
			2	1.50
			5	.54

[a] See figure 1 for sample port location.
[b] Minimum detectable limit.
[c] Values are not mandatory requirements.
[d] No U.S. Public Health Standard.

APPENDIX B – Continued

Cation and Anion Analysis

The data from the cation and anion analysis for the clothes wash tests are given in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Clothes wash test							
				1	2	3	4	5	6	7	8
Cations											
Ammonia	ppm	(b)	1	0.30	0.20	0.20	0.70	0.30	0.21	0.20	<0.20
			2	2.70	12.80	3.52	3.10	6.70	2.12	2.00	3.40
			5	.90	2.20	3.42	2.30	2.80	3.00	2.90	2.60
Calcium	ppm	(b)	1	27.0					35.0		
			2	44.0					52.0		
			5	1.3					1.1		
Anions											
Chloride	ppm	[c] 2.50	1	20.1					20.0		
			2	70.0					54.0		
			5	12.0					<.05		
Cyanide	ppm	0.01	1	0.16					<0.02		
			2	.16					<.10		
			5	.05					<.02		
Fluoride	ppm	1.70	1	1.2					0.50		
			2	1.3					.70		
			5	1.1					.60		
Nitrates and nitrites	ppm	[c] 45.0	1	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50
			2	4.75	<.50	2.40	1.05	<.50	2.60	1.90	3.50
			5	<.50	<.50	<.50	<.50	<.50	<.50	<.50	<.05
Phosphates	ppm	(b)	1	4.5	1.3	1.0	2.5	<0.05	<0.05	<0.05	<0.50
			2	800.0	350.0	450.0	150.0	383.0	388	145	185
			5	23.5	16.0	200.0	4.3	<.05	<.05	<.05	<.50
Sulfate	ppm	[c] 250	1	25					30		
			2	505					475		
			5	<5					265		

[a] See figure 1 for sample port location.
[b] No U.S. Public Health Standard.
[c] Values are not mandatory requirements.

APPENDIX B – Concluded

Organic and Physical Analysis

The data from the organic and physical analysis for the clothes wash tests are presented in the following table:

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Clothes wash test							
				1	2	3	4	5	6	7	8
Organic											
Methylene blue active substances	ppm	0.50	1	0.02	0.01	<0.01	<0.01	0.01	<0.01	0.01	<0.01
			2	<.09	92	150	126	150	240	126	282
			5	.01	.02	<.04	.04	<.01	.01	.01	.01
Carbon chloroform extract	ppm	0.20	1	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
			2	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
			5	(b)	(b)	(b)	(b)	(b)	(b)	(b)	(b)
Phenols	ppm	0.001	1	[c] <0.05							
			2	.20							
			5	.30							
Total organic carbon	ppm	(d)	1	30					16		
			2	293					320		
			5	48					27		
Urea	ppm	(d)	1	<50	<50	<50	<50	<50	<50	<50	<50
			2	<50	<50	<50	<50	<50	<50	<50	<50
			5	<50	<50	<50	<50	<50	<50	<50	<50
Physical properties											
Color	$PtCl_6$ equiv. units	15	1	30	10	<5	20	40	40	40	20
			2	>100	>100	>100	>100	>100	>100	>100	>100
			5	10	<5	<5	<5	<5	<5	<5	<5
Conductivity	Micromhos per centimeter	(d)	1	215	220	260	210	220	240	215	215
			2	190	1000	1900	710	1100	1000	900	750
			5	1	1600	1800	1800	1700	1900	1600	1600
Odor	Threshold number	3.0	1	<3	<3	<3	<3	<3	<3	<3	<3
			2	<3	>3	<3	<3	<3	<3	<3	<3
			5	<3	<3	<3	<3	<3	<3	<3	<3
pH	pH	(d)	1	7.3	6.1	7.3	4.6	7.4	7.4	7.2	7.2
			2	8.2	8.2	7.2	6.7	6.9	7.7	7.4	7.3
			5	3.6	8.2	2.5	2.4	2.6	2.7	2.5	2.5
Total solids	ppm	500	1	237	140	176	224	217	20	844	62
			2	164	7166	5	1220	1350	5550	983	961
			5	112	245	550	577	563	607	468	493
Turbidity	ppm SiO_2 equiv.	5.0	1	15	15	1.0	50	15.0	112	9.0	15.0
			2	50	10	90	80	87.0	1000	75.0	6.5
			5	5.0	1.0	1.0	1.0	1.0	1.0	6.5	2.5

[a] See figure 1 for sample port location.
[b] Analysis not performed.
[c] Minimum detectable limit.
[d] No U.S. Public Health Standard.

APPENDIX C

MICRO-ORGANISM ANALYSIS

Data included in this appendix were obtained from the micro-organism analysis of water samples obtained at various intervals during each test. Total viable cell counts are given for water samples taken at the beginning and end of each wash cycle. The time required to complete a wash cycle averaged 45 minutes. In addition, counts are given for samples taken at the beginning of each process cycle as well as 2 hours after each process cycle was initiated. The data from this analysis are presented in the following table:

Test	Sample time (a)	Micro-organism, number/ml, at sample port[b] –			
		1	2	3	4
Baseline					
Tap water	A	1.13×10^5	(c)	(c)	(c)
	B	2.46×10^2	(c)	(c)	(c)
	C	(c)	2.31×10^5	3.36×10^4	4.0×10^1
	D	(c)	(c)	9.36×10^4	1.5×10^1
Tap water	A	2.58×10^4	(c)	(c)	(c)
	B	3.13×10^2	(c)	(c)	(c)
	C	(c)	3.04×10^5	3.25×10^4	8.9×10^1
	D	(c)	5.08×10^5	4.67×10^7	2.6×10^1
Tap water and detergent	A	1.13×10^4	(c)	(c)	(c)
	B	6.00×10^2	(c)	(c)	(c)
	C	(c)	8.00×10^3	1.14×10^4	2.44×10^2
	D	(c)	1.15×10^4	1.28×10^3	0

[a] A denotes start of wash cycle; B denotes end of wash cycle; C denotes start of processing; D denotes 2 hours after start of processing.

[b] See figure 1 for sample port location.

[c] Sample not taken.

Test	Sample time (a)	Micro-organism, number/ml, at sample port[b] –			
		1	2	3	4
Clothes wash					
1	A	4.75×10^3	(c)	(c)	(c)
	B	1.38×10^2	(c)	(c)	(c)
	C	(c)	1.28×10^6	9.2×10^3	1.8×10^1
	D	(c)	3.51×10^6	1.1×10^5	2×10^0
2	A	3.97×10^3	(c)	(c)	(c)
	B	5.3×10^1	(c)	(c)	(c)
	C	(c)	3.61×10^6	1.21×10^5	0
	D	(c)	1.05×10^7	3.89×10^5	0
3	A	2.03×10^4	(c)	(c)	(c)
	B	5.00×10^1	(c)	(c)	(c)
	C	(c)	3.04×10^6	1.48×10^5	0
	D	(c)	1.13×10^7	1.19×10^6	0
4	A	1.71×10^4	(c)	(c)	(c)
	B	1.67×10^3	(c)	(c)	(c)
	C	(c)	1.02×10^7	3.04×10^5	0
	D	(c)	3.50×10^6	1.29×10^6	0
5	A	4.01×10^4	(c)	(c)	(c)
	B	(c)	(c)	(c)	(c)
	C	(c)	2.87×10^6	1.04×10^5	0
	D	(c)	4.37×10^6	5.16×10^5	0
6	A	1.96×10^5	(c)	(c)	(c)
	B	1.90×10^4	(c)	(c)	(c)
	C	(c)	5.97×10^6	1.14×10^6	0
	D	(c)	3.53×10^6	2.09×10^7	0
7	A	1.14×10^5	(c)	(c)	(c)
	B	8.9×10^3	(c)	(c)	(c)
	C	(c)	7.6×10^6	7.4×10^5	0
	D	(c)	9.4×10^6	2.49×10^5	0
8	No data taken				

[a] A denotes start of wash cycle; B denotes end of wash cycle; C denotes start of processing; D denotes 2 hours after start of processing.

[b] See figure 1 for sample port location.

[c] Sample not taken.

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2. Weinstein, Richard H.: Water Recycling for Domestic Use. Astronaut. & Aeronaut., vol. 10, no. 3, Mar. 1972, pp. 44-51.

3. Anon.: Public Health Service Drinking Water Standards (Revised 1962). Public Health Service Publ. No. 956, U.S. Dep. Health, Education, & Welfare, Sept. 1969.

4. Anon.: Standard Methods for the Examination of Water and Wastewater. Thirteenth ed., Amer. Public Health Assoc., 1971.

TABLE I.- SUMMARY OF WASTE WATER PROCESSED AND FILTERS EXPENDED

Type of waste water	Test	Weight of clothes washed		Volume of water used				Volume of water processed		Process time, hours	Filter expendables		
				Hot		Cold							
		kg	lb	liters	gallons	liters	gallons	liters	gallons		A	C	F
Tap	Baseline	0	0	60.2	15.9	58.3	15.4	101.4	26.8	4.42			
Tap	Baseline	0	0	60.2	15.9	53.0	14.0	104.5	27.6	4.70			
Tap and detergent	Baseline	0	0	58.7	15.5	54.1	14.3	71.2	18.8	7.80			
Tap, detergent, and clothes	1	4.20	9.25	56.0	14.8	50.7	13.4	101.8	26.9	5.30			
	2	4.88	10.75	61.7	16.3	55.6	14.7	74.2	19.6	5.60		1	
	3	4.08	9.00	63.6	16.8	57.5	15.2	42.8	11.3	5.00	1		
	4	4.62	10.50	73.8	19.5	67.8	17.9	119.2	31.5	7.50			1
	5	4.54	10.00	71.9	19.0	66.2	17.5	135.5	35.8	14.30		1	1
	6	2.49	5.50	72.7	19.2	73.8	19.5	92.0	24.3	7.80	1		2
	7	4.62	10.50	73.1	19.3	66.6	17.6	113.6	30.0	7.50			1
	8	3.18	7.00	76.1	20.1	68.5	18.1	102.2	27.0	5.70			1

TABLE II.- SUMMARY OF CHEMICAL AND PHYSICAL WATER ANALYSIS

(a) Metals analysis

Contaminant	Units	U.S. Public Health Standard	Sample port (a)	Test		
				Baseline, tap water	Baseline, tap water and detergent	Clothes wash 6
Arsenic	ppm	0.05	1	[b]<0.10	[b]<0.10	[b]<0.10
			2	[b]<.10	[b]<.10	[b]<.10
			5	[b]<.10	[b]<.10	[b]<.10
Barium	ppm	1	1	<1	<1	<1
			2	<1	<1	<1
			5	<1	<1	<1
Cadmium	ppm	0.01	1	0.01	<0.01	<0.01
			2	<.01	<.02	<.01
			5	<.01	<.01	<.01
Chromium	ppm	0.05	1	<0.01	<0.01	<0.05
			2	<.01	<.01	<.05
			5	<.01	<.01	<.05
Copper	ppm	1	1	0.2	0.1	1.7
			2	<.1	.5	.6
			5	<.1	.5	4.0
Iron	ppm	[c]0.30	1	0.40	0.60	1.00
			2	<.11	.60	1.00
			5	<.20	<.20	1.00
Lead	ppm	0.05	1	<0.05	<0.05	<0.05
			2	<.05	.10	<.05
			5	<.05	<.05	<.15
Magnesium	ppm	(d)	1	3.3	3.7	6.5
			2	3.1	3.8	6.8
			5	.4	.4	1.0
Manganese	ppm	[c]0.05	1	<0.02	0.01	<0.20
			2	<.02	.03	<.10
			5	<.01	<.01	<.05
Nickel	ppm	(d)	1	<0.2	<0.2	<0.2
			2	<.2	<.2	<.2
			5	<.2	<.2	<.2
Selenium	ppm	0.01	1	[b]<0.05	[b]<0.05	<0.10
			2	[b]<.05	[b]<.05	<.10
			5	[b]<.05	[b]<.05	<.10
Silver	ppm	0.05	1	<0.10	<0.10	<0.05
			2	<.10	<.10	<.01
			5	<.10	<.10	<.01
Zinc	ppm	5	1	<0.10	0.10	0.30
			2	<.10	<.05	1.50
			5	<.10	<.05	.50

[a] See figure 1 for sample port location.
[b] Minimum detectable limit.
[c] Values are not mandatory requirements.
[d] No U.S. Public Health Standard.

TABLE II.- SUMMARY OF CHEMICAL AND PHYSICAL WATER ANALYSIS – Continued

(b) Cation and anion analysis

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Test		
				Baseline, tap water	Baseline, tap water and detergent	Clothes wash 1 to 8
Cations						
Ammonia	ppm	(b)	1	0.4	<0.2	<0.3
			2	<.2	.6	4.5
			5	<.2	<.2	2.5
Calcium	ppm	(b)	1	26	26	31
			2	26	26	48
			5	1	2	1
Anions						
Chloride	ppm	[c] 250	1	26	26	20
			2	19	40	62
			5	<5	<5	<6
Cyanide	ppm	0.01	1	<0.02	0.02	<0.09
			2	<.02	<.02	<.13
			5	<.02	<.02	<.04
Fluoride	ppm	1.70	1	1.1	1.1	0.9
			2	1.2	1.2	1.0
			5	<.1	<.1	.9
Nitrates and nitrites	ppm	[c] 45.0	1	<0.5	<0.5	<0.5
			2	<.5	<.5	<2.2
			5	<.5	<.5	<.5
Phosphates	ppm	(b)	1	1	18	<1
			2	1	550	356
			5	1	2	<6
Sulfate	ppm	[c] 250	1	30	25	28
			2	<5	400	490
			5	<5	<5	<128

[a] See figure 1 for sample port location.
[b] No U.S. Public Health Standard.
[c] Values are not mandatory requirements.

TABLE II.- SUMMARY OF CHEMICAL AND PHYSICAL WATER ANALYSIS – Concluded

(c) Organic and physical analysis

Contaminant	Unit	U.S. Public Health Standard	Sample port (a)	Test		
				Baseline, tap water	Baseline, tap water and detergent	Clothes wash 1 to 8
Organic						
Methylene blue active substances	ppm	0.50	1	0.02	0.06	<0.01
			2	<.02	192	146
			5	<.02	.02	<.01
Carbon chloroform extract	ppm	0.20	1	(b)	(b)	(b)
			2	(b)	(b)	(b)
			5	(b)	(b)	(b)
Phenols	ppm	0.001	1	[c] <0.05	[c] <0.05	[c] <0.05
			2	[c] <.05	[c] <.05	.20
			5	[c] <.05	5.90	.30
Total organic carbon	ppm	(d)	1	15	8	23
			2	16	180	307
			5	<5	20	38
Urea	ppm	(d)	1	<50	<50	<50
			2	<50	<50	<50
			5	<50	<50	<50
Physical properties						
Color	$PtCl_6$ equiv. units	15	1	13	15	<26
			2	5	>100	>100
			5	<5	<5	<8
Conductivity	Micromhos per centimeter	(d)	1	203	200	224
			2	203	1200	944
			5	7	9	1486
Odor	Threshold numbers	3.0	1	>3	>3	<3
			2	<3	>3	>3
			5	>3	<3	<3
pH	pH	(d)	1	7.4	7.5	6.8
			2	7.5	9.5	7.5
			5	7.2	5.7	3.2
Total solids	ppm	500	1	200	<100	240
			2	300	1300	2175
			5	<150	<100	458
Turbidity	ppm SiO_2 equiv.	5.0	1	7.1	3.2	29.0
			2	4.9	8.5	175.0
			5	1.3	1.0	2.5

[a] See figure 1 for sample port location.
[b] Analysis not performed.
[c] Minimum detectable limit.
[d] No U.S. Public Health Standard.

TABLE III.- CHEMICAL AND PHYSICAL ANALYSIS TECHNIQUES

Contaminant	Unit	Lower detection limit	Measurement technique
Chemical			
Arsenic	ppm	0.10	Atomic absorption
Barium	ppm	1	Atomic absorption
Cadmium	ppm	.005	Atomic absorption
Chromium	ppm	.01	Atomic absorption
Copper	ppm	.10	Atomic absorption
Iron	ppm	.20	Atomic absorption
Lead	ppm	.05	Atomic absorption
Magnesium	ppm	.001	Atomic absorption
Manganese	ppm	.01	Atomic absorption
Nickel	ppm	.20	Atomic absorption
Selenium	ppm	.05	Atomic absorption
Silver	ppm	.01	Atomic absorption
Zinc	ppm	.05	Atomic absorption
Ammonia	ppm	.20	Atomic absorption
Calcium	ppm	.10	Atomic absorption
Chloride	ppm	5	Specific ion electrode
Cyanide	ppm	.02	Specific ion electrode
Fluoride	ppm	.10	Specific ion electrode
Nitrates and nitrites	ppm	.50	Colorimetric
Phosphates	ppm	.05	Colorimetric
Sulfate	ppm	5	Colorimetric
Methylene blue active substances	ppm	.01	Colorimetric
Carbon chloro- form extract	ppm		
Phenols	ppm	.01	Colorimetric
Total organic carbon	ppm	5	Combustion infrared
Urea	ppm	50	Colorimetric
Physical properties			
Color	$PtCl_6$ equiv. units		Colorimetric
Conductivity	Micromhos per centimeter	0.40	Electrometric
Odor	Threshold number		Subjective
pH	pH		pH meter
Total solids	ppm	100	Flash evaporation
Turbidity	ppm SiO_2 equiv.	.10	Turbidimetry

TABLE IV.- SUMMARY OF MICRO-ORGANISM ANALYSIS

Sample port (a)	Micro-organisms, number/ml	
	Average	Range
1	2.99×10^4	10^1 to 10^5
2	4.30×10^6	10^3 to 10^7
3	3.70×10^6	10^3 to 10^7
4	2.17×10^1	0 to 10

[a] See figure 1 for sample port location.

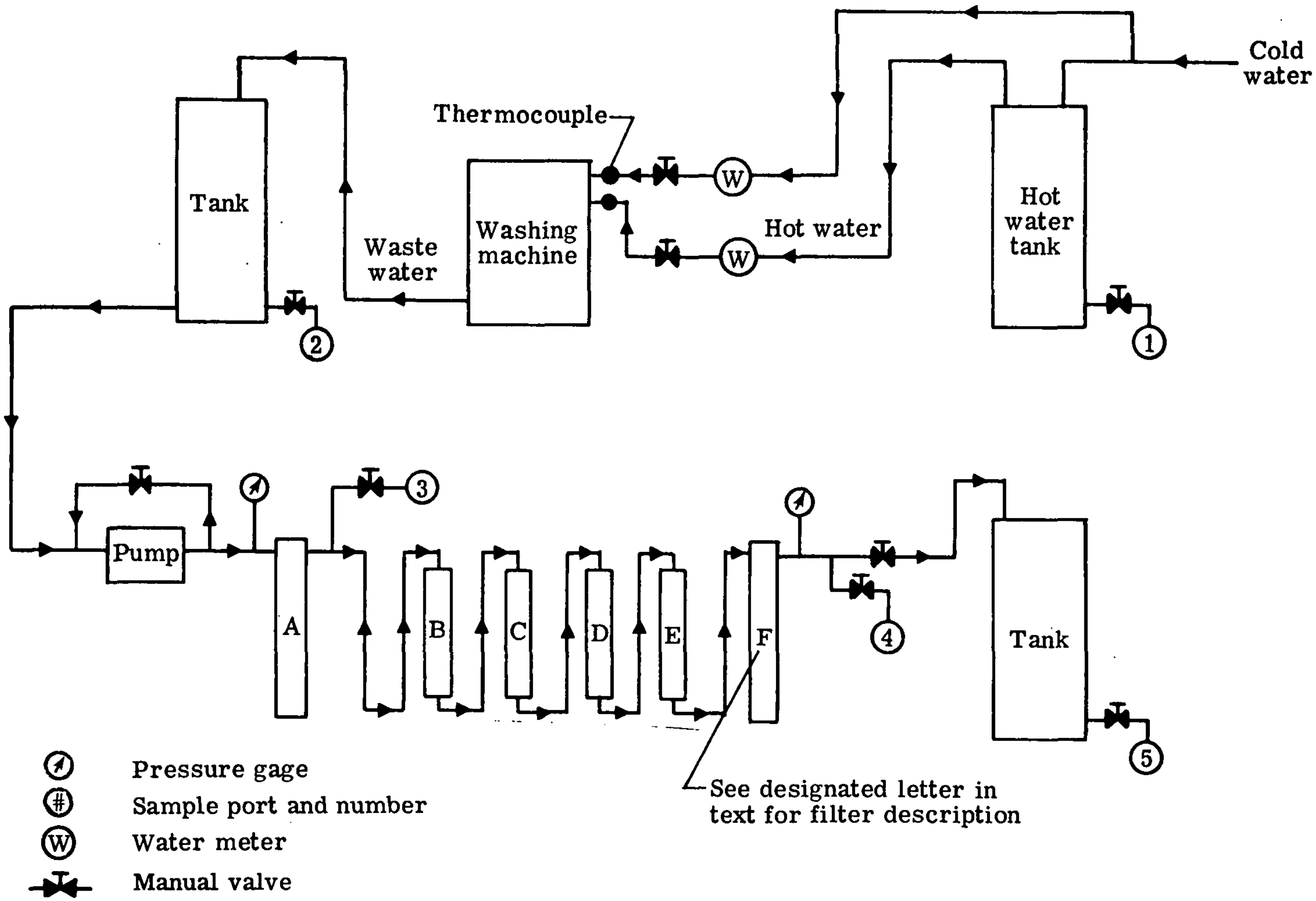

Figure 1.- Schematic drawing of test setup.

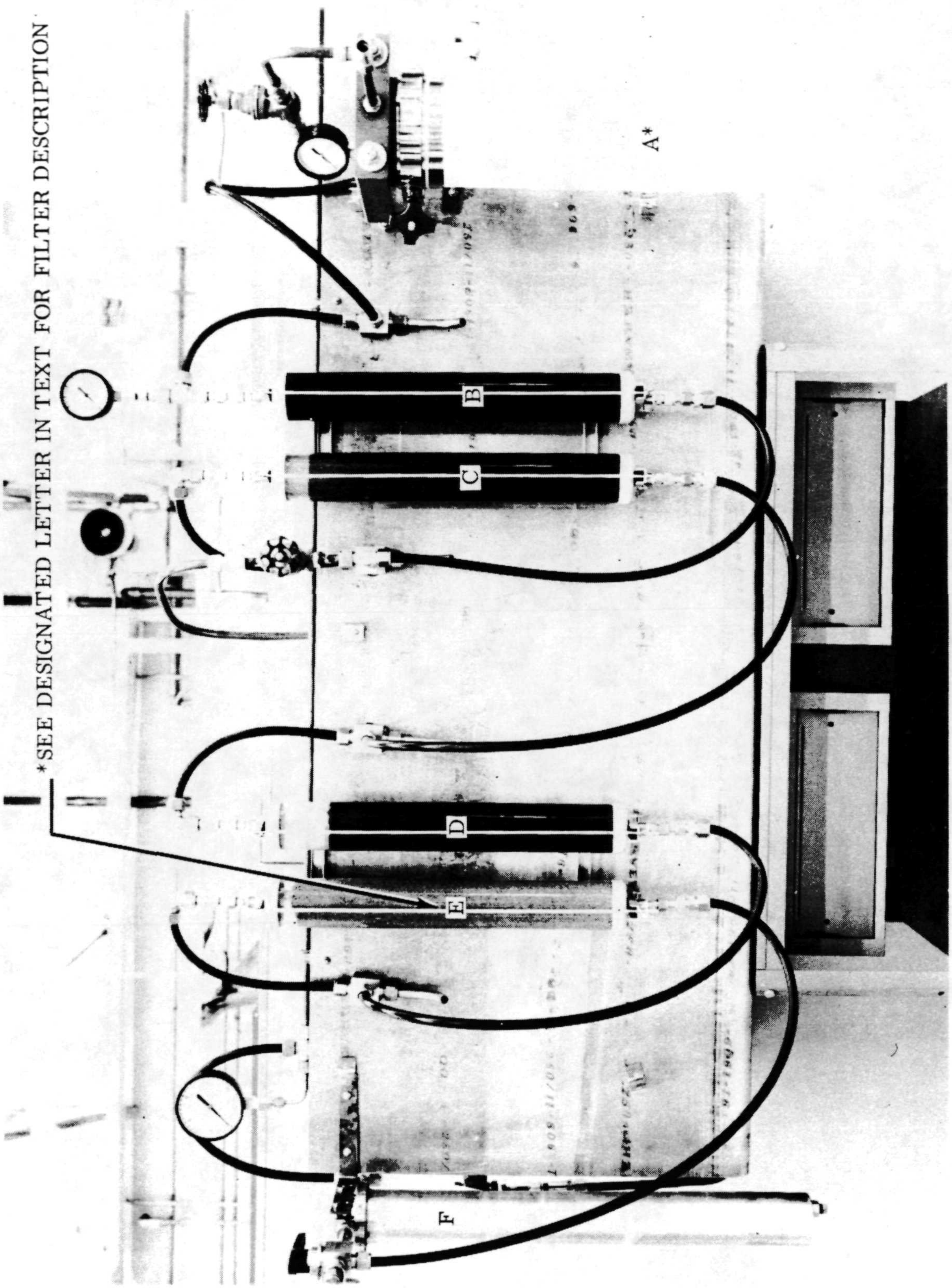

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Figure 2.- Filter arrangement.