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DOMESTIC WASH WATER RECLAMATION FOR REUSE AS COMMODE WATER SUPPLY USING A FILTRATION—REVERSE-OSMOSIS SEPARATION TECHNIQUE

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16. Abstract

A combined filtration—reverse-osmosis water recovery system has been evaluated to determine its capability to reclaim domestic wash water for reuse as a commode water supply. The system produced water that met all chemical and physical requirements established by the U.S. Public Health Service for drinking water with the exception of carbon chloroform extractables, methylene blue active substances, and phenols. It is thought that this water is of sufficient quality to be reused as commode supply water. The filters, which were used to protect the reverse-osmosis unit from plugging, did not sufficiently perform this function because they were not capable of removing particles less than 1 μm in size from the waste water. The process rate of the reverse-osmosis unit was degraded by approximately 46.9 percent for the 2.7 m^3 (713 gallons) of filtered wash water processed. The energy required to process the wash water through the filtration unit and reverse osmosis unit averaged 2.37 kilowatt-hours per cubic meter (0.00897 kilowatt-hour per gallon) and 16.87 kilowatt-hours per cubic meter (0.0639 kilowatt-hour per gallon), respectively. Treatment of the processed water with 5 ppm chlorine was sufficient to reduce the micro-organisms in the commode tank to zero. Efficient dissemination of chlorine was required in order to rapidly inhibit micro-organisms in the processed water tank. The feasibility of using a combined filtration and reverse-osmosis technique for reclaiming domestic wash water has been established. The use of such a technique for wash-water recovery will require a maintenance filter to remove solid materials including those less than 1 μm in size from the wash water. The reverse-osmosis module, if sufficiently protected from plugging, is an attractive low-energy technique for removing contaminants from domestic wash water.

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SUMMARY

A combined filtration—reverse-osmosis water recovery system has been evaluated to determine its capability to reclaim domestic wash water for reuse as a commode water supply. The system produced water that met all chemical and physical requirements established by the U.S. Public Health Service for drinking water with the exception of carbon chloroform extractables, methylene blue active substances, and phenols. It is thought that this water is of sufficient quality to be reused as commode supply water. The filters, which were used to protect the reverse-osmosis unit from plugging, did not sufficiently perform this function because they were not capable of removing particles less than 1 μm in size from the waste water. The process rate of the reverse-osmosis unit was degraded by approximately 46.9 percent for the 2.7 m^3 (713 gallons) of filtered wash water processed. The energy required to process the wash water through the filtration unit and reverse osmosis unit averaged 2.37 kilowatt-hours per cubic meter (0.00897 kilowatt-hour per gallon) and 16.87 kilowatt-hours per cubic meter (0.0639 kilowatt-hour per gallon), respectively. Treatment of the processed water with 5 ppm chlorine was sufficient to reduce the micro-organisms in the commode tank to zero. Efficient dissemination of chlorine was required in order to rapidly inhibit micro-organisms in the processed water tank. The feasibility of using a combined filtration and reverse-osmosis technique for reclaiming domestic wash water has been established. The use of such a technique for wash-water recovery will require a maintenance filter to remove solid materials including those less than 1 μm in size from the wash water. The reverse-osmosis module, if sufficiently protected from plugging, is an attractive low-energy technique for removing contaminants from domestic wash water.

INTRODUCTION

Reverse-osmosis technology developed during the 1950's established the feasibility of the process for the desalination of sea water. (See ref. 1.) Subsequent developments in the early 1960's provided improved membrane configurations that enhanced this technique for the practical reclamation of sea water. (See refs. 2 to 4.) Presently, the increase in demand for sources of water to supply increases in population and industrial needs makes the application of this technology attractive for reclaiming waters other than sea water. Recent developments have established the feasibility of this approach to remove contaminants from wash water expected on manned space missions. (See refs. 5 and 6.) In order to expand this technology and provide information specifically for the reclamation of domestic waste water, a reverse-osmosis unit was tested in combination with a filtration unit at the Langley Research Center to determine its capability to remove contaminants from wash water. The filtration unit was used to protect the reverse-osmosis unit from being plugged by solid material in the wash water. This program was primarily directed toward reclaiming wash water resulting from shower baths and clothes washing in an average size household for its reuse as commode water supply. (See ref. 7.) Because of a lack of standards for commode flush water, the U.S. Public Health Standards (USPHS) given in reference 8 for drinking water were used as a guide to determine water quality. This report presents the data obtained from the test program in which both baseline and wash-water tests were performed over a 12-day period. These data include system operational data as well as chemical, physical, and microbiological analyses of both the wash water and processed water.

SYSTEM DESCRIPTION

Figure 1 shows the arrangement of the filtration, reverse-osmosis, and commode water supply units with the water use facilities. These units are described in the following sections.

Filtration Unit

The filtration unit consisted of a series of five commercially available filters with nominal-particle-size removal ratings of 1 μm, 5 μm, 10 μm, 25 μm, and 50 μm. They were arranged in the order shown in figure 1 to protect the reverse-osmosis unit from plugging and to obtain an estimate of the particle-size distribution in the wash water. Figure 2 shows a typical filter and holder. The filters were made of bleached white cotton wound into diamond structures. Nominal diameter of the filters was 6.35 cm (2.5 in.). Filter lengths were approximately 25.4 cm (10 in.). The filters were supported by porous hollow central cores made of 316 stainless steel. The filters were sealed in 316 stainless-steel housings with compression fit Buna 0-rings. Wash-water filtering was from the outside to the inside of the filter cores. A 0.2461 kW (0.33 hp) centrifugal pump was used to transfer the wash water through the filtration unit. A bypass loop was installed around the pump so that the wash-water pressure could be manually controlled in the filter units.

Reverse-Osmosis Unit

The reverse-osmosis unit consisted of a commercially available membrane module which contained asymmetric hollow fibers made from an aromatic polyamide polymer. (See fig. 3.) Nominal filter inside and outside diameters were approximately 42 μm and 84 μm, respectively. Effective fiber length exposed to the filtered wash water was nominally 0.381 m (1.25 ft). Filtered-wash-water processing was from outside to the inside of the hollow fibers. The unit-rated operating pressure and temperature were 2758 kN/m^2 (400 psi) and 311 K (100° F), respectively. The membranes were enclosed in a shell made of filament-wound fiberglass epoxy. The ends of the shell were sealed with A356-T6 aluminum end plates held in place with PH 15-4 Mo stainless-steel snap rings. The nominal dimensions of the unit were 13.3 cm (5.25 in.) outside diameter by 63.5 cm (25 in.) long. The reverse osmosis unit was operated with a recycle loop in order to obtain multipasses of the filtered wash water through the unit. A 5.59 kW (7.5 hp) multistage centrifugal pump was used to process the water through the reverse-osmosis unit. A bypass loop was installed around the pump in order to control the water pressure manually in the reverse-osmosis unit.

Commode-Water Supply Unit

The commode-water supply unit consisted of a jet pump, 0.061 m^3 (16 gal) pressure tank, the commode water closet, and associated plumbing and valves to connect the processed water tank (tank 3 in fig. 1) to the commode. The jet pump was automatically controlled to maintain the water pressure in the pressure tank between 137.9 and 275.8 kN/m^2 (20 and 40 psi). Water was supplied to the commode water closet within this pressure range on demand. The capacity of this unit was approximately 0.071 m^3 (18.74 gal) of water of which 0.011 m^3 (2.66 gal) was contained in the commode water closet. Most of the plumbing was copper tubing whereas the pressure tank was fabricated from carbon steel.

TEST SETUP AND INSTRUMENTATION

A schematic drawing of the test setup is shown in figure 1. A commercially available household automatic washing machine was used to wash soiled clothes, and showers were taken in a household shower-tub enclosure. A low-volume domestic commode was used in the commode water supply unit. Hot water was supplied to the washing machine and shower-tub enclosure by a commercially available hot-water heater. The hot-water heater as well as the cold-water line were connected to the municipal water supply. The washing machine, shower-tub enclosure, and commode were installed on a raised platform which was approximately 259 cm (8.5 ft) above floor level. The collecting tanks, processing equipment, and hot-water tank were installed on the floor directly beneath the platform. This arrangement facilitated the collection of the wash waters by providing gravity flow of these wastes into water collecting tank 1. (See fig. 1.) The filtration unit was installed upstream of the reverse-osmosis unit for reasons previously discussed. A jet pump was installed downstream of the reverse-osmosis unit to deliver the processed water to the commode water closet as required.

The five commercial integrating-type water meters shown in figure 1 were used to obtain water-use quantities. These meters were read and recorded before and after each water-use function. The two additional flow meters were used to monitor the water flow out of the filtration unit and the water flow in the reverse-osmosis-unit recycle loop. Four dial-type temperature gages were used to obtain temperature measurements. Two of these gages were installed before the water-use facilities to determine the temperatures of both the hot and cold water. The other two gages were used to monitor the inlet water temperatures to both the reverse-osmosis pump and the reverse-osmosis unit. Pressure measurements were obtained with the 10 dial-type pressure gages shown in figure 1. One gage was used to monitor the municipal tap water pressure, six gages were used to monitor the pressure drops across the filters, and three gages were used to monitor the pressure drops across the reverse-osmosis membranes and the recycle loop. Two recording wattmeters, not shown in figure 1, were used to determine the power required to operate both the filtration unit pump and the reverse-osmosis unit pump.

The seven sample ports, located as shown in figure 1, were used for obtaining both chemical and microbial samples for subsequent analysis to determine water quality. All sample ports with the exception of sample port 7 consisted of toggle-type valves and short lengths of stainless-steel tubing. Sample port 7 was the commode water closet itself. Samples were drawn with a sterile pipette.

TEST METHOD

Operational Procedures

The test method used during this investigation was established to provide sufficient time for the wash water to be collected, processed, chlorinated, and flushed through the commode within an 8-hour work day. The daily wash water processed was that quantity resulting from one shower bath and two wash loads of clothes. This combination of wash water was selected because it could be conveniently collected and processed each day to maintain the schedule of events previously discussed. A description of the methods used for the pretest cleanup, the baseline test, and the wash-water tests follow.

Pretest cleanup.- Prior to the start of the 12-day test program, wash water collection tank (tank 1) and the commode water supply unit (tank 3 to the commode water closet) were chlorinated by filling with tap water that had been treated with sodium dichloro-s-triazinetrione to 20 ppm and 5 ppm, respectively, and allowed to sit for approximately 24 hours. This water was then drained into the municipal sewer. Tank 1 and tank 3 were then refilled with hot tap water. A detergent was added and both tanks were thoroughly scrubbed. The water in tank 1 was drained and the water in tank 3 was pumped through the commode loop into the municipal sewer drain. Both tank 1 and the commode loop were flushed with cold tap water and drained. The particulate filters were then charged with cold tap water and allowed to remain in this condition until the start of the tests. No attempt was made to clean the filtration unit, tank 2, or the reverse-osmosis unit because these items were clean and had not been used prior to this investigation.

Test day 1 – Baseline test with tap water.- This test, performed with municipal tap water only, served to determine what contaminants the system itself would contribute to both the wash and processed waters. The tap water was supplied to both the washing machine and the shower tub as they were operated through normal wash cycles. No clothes or detergents were added to the washing machine and the shower tub was unoccupied during these operations. The water from two wash cycles of the clothes washing machine and one bathing simulation through the shower tub was collected in tank 1. Water samples were taken from sample port 1 for chemical and microbial analyses. The filtration unit pump was then started and the bypass valve adjusted to maintain sufficient flow through the filters to allow the water to be processed in approximately 0.75 hours. A water sample for microbial analysis was taken from sample port 2 while the water was being pumped through the filters. After collecting the filtered water in tank 2, water samples were taken from sample port 3 for both chemical and microbial analyses. The residual water remaining in tank 1 was drained. The reverse-osmosis pump was then actuated and both the pump bypass valve and the recycle loop valve were adjusted to maintain the inlet pressure to the reverse-osmosis module at approximately 2758 kN/m^2 (400 psi). Water samples for microbial analysis were taken from sample ports 4 and 5 while the water was being pumped through the module. After collecting the processed water in tank 3, water samples were taken from sample port 6 for both chemical and microbial analyses. Residual water remaining in tank 2 was drained. The commode-water-supply unit was then filled with the processed water and pressurized to 275.8 kN/m^2 (40 psi) with the jet pump. The commode was then flushed at 10-minute intervals until the water in tank 3 was depleted. Water samples were taken hourly from sample port 7 for microbial analysis.

Test days 2 to 12 – wash-water tests.- The wash water processed each day was provided from one shower bath and two wash loads of clothes. The shower baths were taken in the shower-tub enclosure and the clothes were washed in the washing machine. The wash water was collected in this manner prior to the day it was processed for convenience of operation. The method for performing these tests was identical for each day of testing. A description of this method is presented in the following paragraph:

Water samples were taken from sample port 1 for chemical and microbial analyses. The filtration unit pump was then actuated and the bypass valve adjusted to maintain the desired pressure in the filters. A sample for microbial analysis was taken from sample port 2 while the water was being pumped through the filters. After collecting the filtered water in tank 2, water samples were taken from sample port 3 for both chemical and microbial analyses. The residual water remaining in tank 1 was drained. The reverse-osmosis pump was then actuated and both the pump bypass valve and recycle loop valve were adjusted to maintain the inlet pressure to the reverse-osmosis module at approximately 2758 kN/m^2 (400 psi). Water samples for microbial analysis were taken from sample ports 4 and 5 while the water was being pumped through the unit. After collecting the processed water in tank 3, water samples were taken from sample port 6 for both chemical and microbial analyses.

Sufficient chlorine in the form of dichloro-s-triazinetrione was then added through the top of the tank 3 to give a concentration in the processed water of approximately 5 ppm. The water in the tank was allowed to remain static for approximately 1 hour. Water samples were then taken from sample port 6 for chemical and microbial analyses. The commode-water-supply unit was then filled with processed water and pressurized to 275.8 kN/m^2 (40 psi) with the jet pump. The commode was then flushed approximately 21 times at 10-minute intervals. Water samples were taken hourly from sample port 7 for microbial analyses. After processing was completed each day, tank 2 was drained and the recycle loop was flushed with tap water. Residual water remaining in tank 3 was also dumped after each test day was completed.

Sample Analysis Procedures

Chemical and physical analysis.- The chemical and physical quality of the wash, filtered, and processed waters were determined by methods of analysis as described in references 9 to 16. Each sample was analyzed for 36 parameters, which included those specified in the U.S. Public Health Service Drinking Water Standards given in reference 8. Twenty-nine of these were chemical parameters including metals, inorganic ions, and organics, and seven were physical parameters. A summary list of the water analysis techniques used to analyze for these parameters along with their lower detection limits achievable in the Langley water analysis laboratory are given in table I. Approximately

0.003785 m^3 (1 gallon) of water was obtained for each sample analysis. In general, these samples were taken after water was drawn from the system for microbial analysis. Arsenic and selenium in the wash water could not be analyzed to the USPHS specified levels. High solids and organic content in the wash water interfered with the analyses. In addition, no analysis for phenols was made because it was not possible to obtain sufficient sensitivity with present laboratory capability to detect phenols close to the USPHS level of 0.001 ppm.

Micro-organism analysis: Coliform micro-organism counts in the wash, filtered, and processed water were obtained by using the membrane filter technique as described in reference 9. These counts are expressed in numbers per 100 milliliters of sample. The total micro-organism counts were obtained by making 10-fold dilutions of the samples in 0.05 percent peptone water and plating appropriate dilutions on Trypticase soy agar. Colonies were counted after incubation at 308.2 K (95° F) and the results expressed as total number of micro-organisms per milliliter of sample. Approximately 0.0042 m^3 of water was drawn from the system for each analysis.

A sterile pipette was used to obtain water samples from sample port 7. Water samples were obtained from all other sample ports through the toggle valves and short lengths of tubing. These sample ports were heated with an open flame, and then the toggle valves were opened to allow water to flush the ports prior to taking the samples. After the samples were taken, the sample ports were reheated with an open flame to dry the tubing.

RESULTS AND DISCUSSION

Summaries of the operational data for the filtration and reverse osmosis units are given in tables II and III, respectively. Table IV gives a summary of the commode-water-supply unit data and table V gives a summary of the wash water collected. Tables VI and VII show summaries of the wash and recovered waters for the baseline test and the wash water tests, respectively. Appendix A contains all the chemical and physical data for the 12 days of testing. Table VIII gives a summary of the material removed with the filtration unit. Table IX gives a summary of viable micro-organism counts by sample port location. These values were obtained by averaging the data for all the tests for these sample ports as given in appendix B.

System Operational Data

A summary of the filtration unit operational data is given in table II. During the wash-water tests (test days 2 to 12) a total of 3.38 m^3 (893 gallons) of wash water was processed over an 11-day period at an average process rate of 0.2937 m^3 per hour

(77.6 gallons per hour). Average daily process time was 1.5 hours. The power required to operate the pump averaged 0.541 kW. The energy required to process the wash water was 2.37 kilowatt-hours/m^3 (0.00897 kilowatt-hours/gallon). During test day 4, it was found that the pump began to leak when the inlet pressure to the filters exceeded 344.7 kN/m^2 (50 psi). Therefore, the inlet pressure was maintained at 275.8 kN/m^2 (40 psi) for test days 5 to 12. The filters were changed twice during the wash-water tests at test day 4 and test day 9. The water processed averaged 1.147 m^3 (303 gal) before each set of filters were changed. The frequency of filter changes could be decreased if consideration were given to a system design which specified 24 hours of continuous operation at higher operational pressures. For the purposes of this investigation, the filters were changed when the time required to process the daily wash water at an operational pressure of 275.8 kN/m^2 (40 psi) would not allow for the completion of all test functions in an 8-hour work shift. The filtration unit used in this investigation allowed the reverse-osmosis unit to operate without plugging for sufficient duration to obtain performance data. However, the use of this type of filtration unit in a system to remove contaminants from domestic wash water is not attractive because of the need to change the filters frequently.

A summary of the reverse-osmosis unit operational data is given in table III. A total of 2.7 m^3 (713 gal) of wash water was processed at an average process rate of 0.319 m^3 per hour (84.2 gallons per hour). Average daily process time for the 11 days of wash-water testing was 0.93 hours. The power required to operate the pump averaged 5.38 kW. The energy consumed to process the wash water averaged 16.87 kW-hr/m^3 (0.0639 kW-hr/gal). Approximately 81 percent of the wash water pumped through the particulate filters was processed through the reverse-osmosis unit. The quantity of wash water processed could be increased by providing cooling to maintain the waste-water inlet temperature to the reverse-osmosis module below the unit maximum rated operational temperature of 311.0 K (100° F). The wash water was heated by energy input from the reverse-osmosis pump when the wash-water level in tank 2 was reduced below 0.0757 m^3 (20 gallons). The temperature of the wash water entering the reverse-osmosis module averaged 300.1 K (80.5° F) during the wash-water tests. The flow of wash water through the recycle loop averaged 0.0096 m^3 per minute (2.53 gallons per minute). The inlet pressure to the reverse-osmosis module and the outlet pressure in the recycle loop averaged 2758 kN/m^2 (400 psi) and 2275 kN/m^2 (330 psi), respectively. Process rate degradation of 46.8 percent was indicated by comparison of the baseline tests performed before and after the wash-water tests. The reduction in process rate indicates that the filtration unit was not removing sufficient material from the wash water to prevent the reverse-osmosis membrane from plugging. Although the reverse-osmosis unit had sufficient process capacity to recover the daily wash water provided by an average size family, it will not be a practical unit until the plugging problem is solved.

A nonplugging reverse-osmosis membrane unit would be an attractive low-energy technique for removing contaminants from domestic wash water.

A summary of the commode water supply unit data is shown in table IV. A total of 2.646 m^3 (699 gal) of processed water was treated with a 10 000 ppm solution of dichloro-s-triazinetrione, a chlorination agent, to control micro-organisms in the commode flush loop. Approximately 1359 milliliters of the solution was used during this investigation to give an average concentration in the water treated of 5.1 ppm. A total of 2.42 m^3 (640 gal) of the chlorinated water was used to flush the commode. The water used per commode flush averaged 0.0105 m^3 (2.78 gal). The commode was flushed approximately 21 times per day to simulate the use frequency of a four-member family. No wastes were deposited in the commode during this investigation.

Collection and Quality of Untreated Wash Water

A summary of the wash water collected is shown in table V. Wash water collected each day during this investigation was a composite from one shower bath and two clothes-wash loads. The total amount of wash water collected each day averaged 0.4020 m^3 (106.2 gal); 0.0264 m^3 (7 gal) hot water and 0.0238 m^3 (6.3 gal) cold water from shower baths, and 0.0829 m^3 (21.9 gal) hot water and 0.2692 m^3 (71.1 gal) cold water from two clothes-wash loads. The hot-water temperature averaged 338 K (149° F) and the cold-water temperature averaged 286 K (55° F). A commercial bath soap, containing 1.5 percent 3,4,4'-trichlorocarbanilide active ingredient, was used for the shower baths. The average amount of soap used per bath was 2.73 grams (0.096 oz). The detergent used for clothes-washing was a commercial-type biodegradable detergent. An average of 7.85 grams (0.277 oz) of detergent was used per clothes-wash load. Clothes washed during the test consisted of linens, and personal garments from children and adults. The average weight of the clothes washed daily was 7.5 kg (16.54 lb).

The wash-water chemical analysis data for the 12 days of testing is shown in appendix A. The data shown for the first day correspond to the baseline run with tap water only. The baseline data are summarized in table VI of this report. It may be noted that iron and carbon chloroform extractable materials in the tap water exceeded the USPHS levels.

The wash-water data from the remaining 11 days were averaged and presented in table VII. The data show that the waste water met 12 out of the 23 USPHS standards for drinking water. These were barium, cadmium, chromium, copper, manganese, silver, zinc, chloride, fluoride, nitrate and nitrite, sulfate, and odor. The following parameters of the wash water had concentrations greater than the USPHS Standards: iron, lead, carbon chloroform extractables (greases and oils), methylene blue active substances, color, total solids, and turbidity.

Collection and Quality of Processed Wash Water

The wash water was processed daily through five particulate filters of 1, 5, 10, 25, and 50 μm pore size each. This processing was followed by reverse-osmosis processing.

The amount of solids removed by the filters is shown in table VIII. A total of 298 g (0.65716 lb) of solids were removed after 2.29 m^3 (606 gallons) of wash water were processed. This amount was obtained by weighing the dried filters before the beginning of the test and at the fourth and ninth days of processing. An average of 129 ppm of solids was removed. This value correlates well with the average of 103 ppm solids removed as obtained by the total-solids-analysis evaporation technique used in analysis of the wash water and the filtered water for the same test period.

The percent solids in each particle size range was calculated from the weight gain of each filter. The following percentages in each particle size range were obtained: 10.7 percent were greater than 50 μm in size, 15.7 percent were between 50 μm and 25 μm, 15.4 percent were between 25 μm and 10 μm, 36.6 percent were between 10 μm and 5 μm, and 21.5 percent were between 5 μm and 1 μm.

Particles smaller than the specified filter pore size were likely retained by the individual filters as they started to accumulate solids; therefore, the percentages are an estimate rather than an absolute value of the distribution of various particle sizes removed from the wash water.

The data from the chemical analysis of the filtered water is shown in appendix A and a summary of the 11 days of wash-water processing is shown in table VII. Reductions in concentration resulting from the filtration process are shown by comparing the columns headed "Wash water" and "Filter processed water." This comparison may then be viewed in percents under the column headed "Percent reduction." Paired t tests as given in reference 17, using a 95-percent confidence value, were applied to the 11-day test data to determine whether these reductions were significant. Eighteen of the parameters listed exhibited significant decreases in concentrations after filtration; they were: iron, magnesium, zinc, ammonium, calcium, chloride, phosphates, potassium, sodium, sulfate, carbon chloroform extractables, methylene blue active substances, total organic carbon, color, conductivity, odor, total solids, and turbidity.

Parameters which still did not fall within the USPHS drinking water standards after filtration were iron, lead, carbon chloroform extractables, methylene blue active substances, color, total solids, and turbidity. Copper, lead, magnesium, and zinc show increases in concentration in the filtered water. These increases may be due to contamination from the pipes transporting the water in the process unit. It is of interest to note that 90 percent of the solid material in the wash water passed through the 1 μm filter.

The data summarized in table VII indicates that the reverse-osmosis unit produced water that met the USPHS standards for drinking water with the exception of three parameters: carbon chloroform extractables, methylene blue active substances, and phenols. The reverse-osmosis unit was effective in removing copper, iron, lead, magnesium, and zinc from the filtered water as indicated by the percent reductions under reverse osmosis in table VII. Other metals were not present in measurable concentrations; therefore, no changes in their concentrations were detected. Other parameters were significantly reduced in concentration by the reverse-osmosis process. Reductions of 90 percent or above were obtained for calcium, fluoride, phosphates, potassium, sodium, sulfate, methylene blue active substances, total organic carbon, color, conductivity, and turbidity. Ammonium, chloride, carbon chloroform extractables, and total solids were reduced over 80 percent, the odor was reduced by 57.1 percent, and the pH was lowered by 4.0 percent. These values were obtained by comparing the filtered-water data with the reverse-osmosis processed-water data after applying paired t tests to determine their significance. It is thought that this water is of sufficient chemical and physical quality to be reused as a commode water supply. The percent-reduction figures for the reverse-osmosis system were based on water recovery of 80.8 percent or recovery of a daily average of 0.245 m^3 (64.8 gallons) of water from a daily average of 0.304 m^3 (80.2 gallons) of filtered water.

Micro-Organism Control

Table IX shows both the averaged total viable micro-organism counts and the averaged viable coliform counts for the water analyzed during this investigation. These values were obtained by averaging the micro-organism counts given for each sample port location as shown in appendix B.

The filtration unit was not effective in reducing micro-organism counts. This result was not unexpected since filter sizes in the submicron range are required to remove micro-organisms. The minimum size filter used in this evaluation was 1 μm. The reverse-osmosis unit reduced both the total and coliform counts by two logs from 6.75 and 7.25 to 4.71 and 5.34 respectively.

The addition of 5 ppm chlorine in the form of dichloro-s-triazinetrione to the processed water tank 3 was sufficient to reduce the micro-organism counts in the commode water closet to zero. However, the static technique used to disseminate the chlorine in tank 3 was not sufficient to eliminate the organisms from the storage tank. Rapid dissemination of the chlorine with an active mixing technique will be required to accomplish this.

As the total system was not sterilized prior to the start of the test, high bacterial counts were evident in the baseline samples. The high cell counts in the wash water were attributed to storing the water overnight (approximately 18 hours) at room temperature prior to processing.

CONCLUDING REMARKS

A filtration—reverse-osmosis system has been evaluated to determine its capability to reclaim water from domestic wash water for reuse as commode water supply. It is thought that the system produced water of sufficient quality to be reused for this purpose. The system produced water that met all the chemical and physical requirements established by the U.S. Public Health Service for drinking water with the exception of carbon chloroform extractables, methylene blue active substances, and phenols. The phenols analysis was not performed because of the lack of capability to measure the concentration level specified for this standard. The chlorine treatment of the processed water was effective in reducing the micro-organisms in the commode water closet to zero. Approximately 90 percent of the solid material in the wash water was less than 1 μm in size. Therefore, the filtration unit was only partially effective in protecting the reverse-osmosis unit from plugging. Process-rate degradation of the reverse-osmosis unit for the 2.7 m^3 (713 gal) of filtered water processed was approximately 46.8 percent. The wash water processed through the filtration unit averaged 1.147 m^3 (303 gal) before each set of filters were changed. The energy consumed in processing the wash water through the filters averaged 2.37 kilowatt-hours per cubic meter (0.00897 kilowatt-hour per gallon) at an average process rate of 0.2937 cubic meter per hour (77.6 gallons per hour). The reverse-osmosis unit was operated at an average inlet pressure of 2758 kN/m^2 (400 psi). Filtered water was processed at an average process rate of 0.319 cubic meter per hour (84.2 gallons per hour). Associated energy consumption averaged 16.87 kilowatt-hours per cubic meter (0.0639 kilowatt-hour per gallon). The reverse-osmosis unit, if sufficiently protected from plugging, is an attractive, low-energy technique for removing contaminants from domestic wash water.

Langley Research Center,
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Hampton, Va., January 29, 1974.

APPENDIX A

CHEMICAL AND PHYSICAL WATER DATA

Data included in this appendix were obtained from the chemical and physical water analysis for both the baseline and wash-water tests. Data are presented which show the condition of the water before and after processing. The analysis includes 22 of the 23 parameters listed in reference 8 for drinking water. In addition, data are included for 14 other parameters which were selected to give additional system performance information.

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

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Metals											
				Baseline for test day	Wash water for test day –										
				1	2	3	4	5	6	7	8	9	10	11	12
Arsenic	ppm	0.05	1	0.01	Analysis not performed										
			3	0.01											
			6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Barium	ppm	1.0	1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Boron	ppm	None	1	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			3	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
			6	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
Cadmium	ppm	0.01	1	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			3	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
			6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Chromium	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			3	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Copper	ppm	1.0	1	0.1	0.12	0.08	0.09	0.12	0.12	0.12	0.08	0.14	0.12	0.12	0.11
			3	0.1	0.18	0.12	0.19	0.12	0.12	0.11	0.08	0.08	0.10	0.12	0.10
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Iron	ppm	0.30	1	0.40	1.1	1.5	0.71	0.88	1.2	0.30	0.59	0.96	1.3	0.93	1.0
			3	0.18	0.74	1.4	1.0	0.72	0.82	0.42	0.44	0.80	1.0	0.87	0.78
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Lead	ppm	0.05	1	0.01	0.06	0.08	0.09	0.08	0.08	0.06	0.04	0.06	0.07	0.05	0.04
			3	0.01	0.06	0.08	<0.01	0.07	0.08	0.06	0.08	0.01	0.07	0.06	0.05
			6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	0.01	0.01	0.01	0.01	0.01	0.01
Magnesium	ppm	None	1	1.6	2.1	2.1	2.1	1.9	1.9	1.5	1.8	2.1	2.2	2.1	2.0
			3	1.7	2.0	1.9	1.9	1.9	1.9	1.6	1.7	2.1	2.1	2.1	2.0
			6	0.2	0.4	0.1	0.1	0.06	0.05	0.05	0.05	0.07	0.07	0.04	0.07
Manganese	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			3	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Mercury	ppm	None	1	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
			3	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
			6	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Nickel	ppm	None	1	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
			3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
			6	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Selenium	ppm	0.01	1	<0.01	Analysis not performed										
			3	<0.01											
			6	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
Silver	ppm	0.05	1	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			3	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Zinc	ppm	5.0	1	0.43	1.1	1.2	1.7	1.1	0.96	0.60	0.92	0.96	0.84	0.86	1.0
			3	0.30	1.1	1.1	1.4	0.95	0.94	0.58	0.85	1.0	0.82	0.80	0.93
			6	0.04	0.04	0.03	0.04	0.25	0.03	0.10	0.02	0.05	0.03	0.08	0.03

The data from the ions analysis are presented in the following table:

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Ions											
				Baseline for test day	Wash water for test day –										
				1	2	3	4	5	6	7	8	9	10	11	12
Ammonium	ppm	None	1	<0.05	0.66	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.22	0.55	0.89	1.4
			3	0.09	0.17	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.36	0.12	0.64	1.0
			6	0.12	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	0.11	0.07	0.10	0.15
Calcium	ppm	None	1	24	26	29	24	28	30	26	27	29	30	28	30
			3	25	24	28	24	26	27	25	26	27	28	26	28
			6	1.0	2.0	0.5	0.5	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4
Chloride	ppm	250	1	15	35	31	25	27	25	21	23	27	32	32	26
			3	16	33	29	26	23	24	22	23	24	25	31	27
			6	4.7	6.3	4.4	5	3.9	3.5	3.6	3.5	3.2	4.2	5.4	7.4
Chlorine	ppm	None	1	0.15	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			3	0.16	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
			6	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
Cyanide	ppm	0.2	1	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
			3	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
			6	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02	<0.02
Fluoride	ppm	1.70	1	0.92	0.85	0.96	0.92	0.92	0.88	0.89	0.78	0.96	0.88	0.95	0.89
			3	0.96	0.87	0.96	0.89	0.89	0.80	0.92	0.94	0.93	0.85	0.98	0.92
			6	0.12	0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Nitrate and nitrite	ppm	45.0	1	0.4	0.9	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
			3	0.4	0.7	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
			6	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2
Phosphates	ppm	None	1	1.6	200	210	180	200	210	200	180	160	180	180	180
			3	1.3	150	190	180	200	180	170	160	180	150	160	150
			6	0.3	1.7	3.0	4.0	3.2	3.9	3.8	3.5	5.2	5.1	3.8	6.4
Potassium	ppm	None	1	1.3	4.8	3.2	4.4	3.3	3.7	2.7	3.3	4.0	4.6	4.5	5.5
			3	1.2	4.3	3.2	4.0	3.4	3.4	2.8	3.1	4.1	4.1	4.4	5.1
			6	0.85	0.55	0.22	0.22	0.22	0.22	0.15	0.20	0.28	0.28	0.35	0.40
Sodium	ppm	None	1	8.8	110	120	115	115	115	115	105	105	115	125	105
			3	7.0	95	110	105	110	120	100	100	105	100	105	95
			6	4.0	6.8	6.1	6.3	6.8	7.1	6.6	7.2	8.7	8.5	7.1	7.6
Sulfate	ppm	250	1	39	80	85	100	120	120	110	110	110	100	100	110
			3	37	91	32	100	120	100	90	110	110	90	100	90
			6	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

The data from the organic and physical analyses are presented in the following table:

Parameter	Unit	U.S. Public Health Standard	Sample port (see fig. 1)	Baseline for test day	Wash water for test day –										
				1	2	3	4	5	6	7	8	9	10	11	12
Organic analysis															
Carbon chloroform extract	ppm	0.2	1	30	31	19	26	27	27	15	14	24	21	21	23
			3	30	16	12	19	7	9	12	16	17	12	17	16
			6	29	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Methylene blue active substances	ppm	0.5	1	0.1	50	40	44	44	39	60	42	48	51	49	62
			3	0.1	29	38	36	47	35	45	42	40	38	45	48
			6	1.0	1.2	2.4	2.8	3.2	0.6	2.4	2	3.2	3.0	2.7	2.8
Phenols	ppm	0.001	1	Analysis not performed											
			3												
			6												
Total organic carbon	ppm	None	1	<5	76	62	86	75	120	43	54	82	59	95	85
			3	<5	45	29	49	42	42	38	31	77	56	65	72
			6	<5	<5	<5	<5	7	5	<5	<5	6	5	5	5
Urea	ppm	None	1	<0.05	17.1	2.1	1.0	2.8	2.5	1.1	1.4	5.1	13.0	10.2	11.0
			3	<0.05	16.4	2.1	<0.05	4.8	2.2	1.0	2.2	5.8	11.5	8.0	9.2
			6	<0.05	10.8	2.2	<0.05	8.1	4.9	1.7	1.8	7.7	11.2	9.6	9.4
Physical analysis															
Color	$PtCl_6$ units	15	1	<5	>100	>100	>100	>100	>100	>100	60	>100	>100	80	>100
			3	<5	70	>100	>100	70	>100	30	30	80	70	60	60
			6	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5	<5
Conductivity	Micromhos per centimeter	None	1	180	480	510	460	480	520	480	440	460	450	500	500
			3	182	430	460	440	480	485	460	430	450	440	460	450
			6	34	48	34	34	32	35	33	34	38	46	48	51
Odor	Threshold number	3	1	1	2	2	2	2	3	2	2	4	4	4	4
			3	1	1	1	2	2	3	2	2	2	2	2	4
			6	1	1	1	1	1	1	1	1	1	2	1	2
pH	Units	None	1	7.2	7.4	7.5	7.5	7.7	7.3	7.3	7.3	7.2	7.3	7.5	7.3
			3	6.8	7.3	7.3	7.4	7.6	7.3	7.5	7.3	7.1	7.4	7.5	7.2
			6	6.7	7.1	7.0	6.9	7.3	7.1	7.5	7.0	7.2	7.0	7.1	7.2
Suspended solids	ppm	None	1	<100	<100	134	<100	<100	<100	<100	<100	<100	<100	<100	<100
			3	<100	<100	109	<100	<100	<100	<100	<100	<100	<100	<100	<100
			6	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100	<100
Total solids	ppm	500	1	239	867	765	700	712	778	657	654	650	641	694	595
			3	213	700	661	646	634	613	562	515	631	606	616	593
			6	<100	<100	<100	<100	<100	<100	<100	<100	110	110	<100	306
Turbidity	ppm, SiO_2 equivalent	5	1	1.8	92	90	99	70	69	42	52	78	78	70	80
			3	0.47	47	52	63	34	28	26	20	48	43	48	43
			6	0.10	0.37	0.58	0.66	0.39	0.56	0.28	0.25	0.5	0.5	0.47	0.44

APPENDIX B

MICRO-ORGANISM DATA

Included in this appendix are data obtained from the micro-organism analyses of water samples obtained at various intervals during the tests. Data are presented which show total viable cell counts as well as viable coliform counts for both the wash and processed waters.

The total number of micro-organisms $(\log_{10})$ per milliliter are given in the following table:

Type of test	Test day	Sampling port (see fig. 1)										
		1	2	3	4	5	6 (a)	6 (b)	7 (c)	7 (c)	7 (c)	7 (c)
Baseline tap water	1	0	0	3.64	4.11	3.11	3.23	(d)	4.91	4.46	4.11	3.89
Wash water	2	6.65	6.79	6.91	6.56	4.56	4.86	1.93	4.81	0	0	0
	3	7.14	6.87	6.92	4.93	5.04	0	0	0	0	0	0
	4	7.04	6.76	6.11	7.32	5.17	4.85	0	0	0	0	0
	5	6.43	6.11	6.17	6.34	4.04	4.59	0	0	0	0	0
	6	6.91	6.14	6.20	6.39	4.32	4.46	3.30	0	0	0	0
	7	6.55	6.11	6.20	6.49	4.55	4.57	0	0	0	0	0
	8	5.69	6.65	5.73	(d)	(d)	4.46	2.72	0	0	0	0
	9	6.32	6.30	6.17	6.25	4.27	4.69	2.57	0	0	0	0
	10	6.73	6.50	6.60	6.60	4.62	4.72	3.92	0	0	0	0
	11	6.61	6.41	6.53	6.67	4.68	4.74	0	2.38	1.69	0	0
	12	6.93	6.46	6.60	6.49	4.72	5.04	0	2.00	3.27	1.25	0

[a]Sample taken before chlorination.

[b]Sample taken 1 hour after chlorination.

[c]Hourly samples.

[d]Analysis not performed.

The number of coliforms $(\log_{10})$ per 100 milliliter are given in the following table:

Type of test	Test day	Sampling port (see fig. 1)										
		1	2	3	4	5	6 (a)	6 (b)	7 (c)	7 (c)	7 (c)	7 (c)
Baseline tap water	1	0	0	0	(d)	1.77	1.49	(e)	0	0	0	0
Wash water	2	0	4.80	5.17	6.11	3.83	3.90	0	0	0	0	0
	3	(e)	5.86	5.97	6.71	4.73	4.92	0	0	0	0	0
	4	5.51	7.11	6.54	7.32	5.38	5.04	0	0	0	0	0
	5	(d)	(d)	(d)	7.70	5.60	5.77	0	0	0	0	0
	6	(d)	7.77	7.70	7.60	5.67	5.77	(d)	0	0	0	0
	7	7.81	6.79	6.83	7.27	5.43	5.67	0	0	0	0	0
	8	6.25	7.90	6.83	(e)	(e)	5.17	(d)	0	0	0	0
	9	8.04	6.97	7.30	7.20	5.34	5.54	(d)	0	0	0	0
	10	7.97	6.98	6.94	6.93	5.07	5.56	(d)	0	0	0	0
	11	7.00	6.00	7.11	7.11	5.46	5.46	0	0	0	0	0
	12	7.86	6.77	7.07	7.00	5.04	5.69	0	0	(d)	0	0

[a]Sample taken before chlorination.

[b]Sample taken 1 hour after chlorination.

[c]Hourly samples.

[d]Too numerous to count.

[e]Analysis not performed.

REFERENCES

1. Breton, Ernest Joseph, Jr.: Water and Ion Flow Through Imperfect Osmotic Membranes. Res. and Dev. Progress Rep. No. 16, U.S. Dep. Interior, Apr. 1957.
2. Monsanto Boston Lab.: Investigation and Preparation of Polymer Films To Improve the Separation of Water and Salts in Saline Water Conversion. PB 181467, U.S. Dep. Commerce, Dec. 1962.
3. Fisher, R. E.; Sherwood, T. K.; and Brian, P. L. T.: Salt Concentration at the Surface of Tubular Reverse Osmosis Membranes. Res. and Dev. Progress, Rep. No. 141 (PB 177203), U.S. Dep. Interior, Sept. 1965.
4. Lonsdal, H. K.; Merten, U.; Riley, R. L.; and Vos, K. D.: Reverse Osmosis for Water Desalination. Res. and Dev. Progress Rep. No. 150, U.S. Dep. Interior, Oct. 1965.
5. Hester, J. C.; and Brandon, C. A.: Feasibility Demonstration of a Hyperfiltration Technique To Reclaim Shower Wastewater at Elevated Temperatures. NASA CR-112127, 1972.
6. Jasionowski, W. J.; and Bambenek, R. A.: Evaluation of RO Modules for the SSP ETC/LSS. 73-ENAs-22, Amer. Soc. Mech. Eng., July 1973.
7. Bailey, James R.; Benoit, Richard J.; Dodson, John L.; Robb, James M.; and Wallman, Harold: A Study of Flow Reduction and Treatment of Waste Water From Households. Water Pollut. Contr. Res. Ser. 11050FKE, Fed. Water Quality Admin., U.S. Dep. Interior, Dec. 1969.
8. Anon.: Public Health Service Drinking Water Standards. Public Health Service Publ. No. 956, U.S. Dep. Health, Education, and Welfare, Revised 1962.
9. Anon.: Standard Methods for the Examination of Water and Wastewater. Thirteenth ed., Amer. Public Health Assoc., c.1971.
10. Anon.: Methods for Chemical Analysis of Water and Wastes 1971. 16020-07/71, Environmental Protection Agency, 1971.
11. Slavin, Walter: Atomic Absorption Spectroscopy. Interscience Publ., c.1968.
12. Douglas, L. A.; and Bremner, J. M.: Colorimetric Determination of Microgram Quantities of Urea. Anal. Lett., vol. 3, no. 2, c.1970, pp. 79-87.
13. Dalton, Edward F.; and Malanoski, A. J.: Note on the Determination of Arsenic by Atomic Absorption by Arsine Generation Into an Argon-Hydrogen Entrained Air Flame. Atomic Absorption Newsletter, vol. 10, no. 4, July-Aug. 1971, pp. 92-95.
14. Anon.: Instruction Manual – Halide Electrodes, Model 94-17, Model 94-35, Model 94-53. Second ed., Orion Res., Inc., c.1967.

15. Dixon, Wildrid J.; and Massey, Frank J., Jr.: Introduction to Statistical Analysis. Third Ed., McGraw-Hill Book Co., Inc., 1969.

16. Anon.: Instruction Manual – Ammonia Electrode Model 95-10. Orion Res., Inc., c.1971.

17. Anon.: Instruction Manual – Cyanide Activity Electrode Model 94-06. Orion Res., Inc., c.1972.

TABLE I.- CHEMICAL AND PHYSICAL ANALYSIS TECHNIQUES

Parameter	Unit	Lower detection limit	Measurement technique	Reference
Arsenic	ppm	0.005	Atomic absorption-flameless	13
Barium	ppm	1.0	Atomic absorption	9
Boron	ppm	1.0	Colorimetric	9
Cadmium	ppm	.01	Atomic absorption	9
Chromium	ppm	.05	Atomic absorption	10
Copper	ppm	.05	Atomic absorption	10
Iron	ppm	.05	Atomic absorption	10
Lead	ppm	.01	Atomic absorption-extraction	10
Magnesium	ppm	.01	Atomic absorption	10
Manganese	ppm	.05	Atomic absorption	10
Mercury	ppm	.001	Atomic absorption	10
Nickel	ppm	.1	Atomic absorption	11
Selenium	ppm	.005	Atomic absorption-flameless	13
Silver	ppm	.05	Atomic absorption	10
Zinc	ppm	.02	Atomic absorption	10
Ammonium	ppm	.05	Specific ion electrode	14
Calcium	ppm	.01	Atomic absorption	10
Chloride	ppm	5.0	Specific ion electrode	15
Chlorine	ppm	.05	Colorimetric	9
Cyanide (free)	ppm	.02	Specific ion electrode	16
Fluoride	ppm	.05	Specific ion electrode	10
Nitrate and nitrite	ppm	.2	Colorimetric	10
Phosphates (total)	ppm	.1	Colorimetric	10
Potassium	ppm	.01	Atomic absorption	10
Sodium	ppm	.01	Atomic absorption	10
Sulfate	ppm	10.0	Turbidimetric	10
Carbon chloroform extract	ppm	.2	Gravimetric	10
Methylene blue active substances	ppm	.01	Colorimetric	10
Phenols	ppm	.005	Colorimetric	10
Total organic carbon	ppm	5.0	Combustion infrared	10
Urea	ppm	1.0	Colorimetric	10
Color	$PtCl_6$ equivalent units	5.0	Colorimetric	10
Conductivity	Micromhos per centimeter	.05	Electrometric	10
Odor	Threshold number	------	Subjective	10
pH	pH units	------	Electrometric	10
Suspended solids	ppm	100.0	Gravimetric	10
Total solids	ppm	20.0	Gravimetric	10
Turbidity	ppm, SiO_2 equivalent	0.1	Turbidimetry	10

TABLE II.- SUMMARY OF FILTRATION UNIT OPERATIONAL DATA

Test	Test day	Operating pressures obtained from gage[a] –												Pump power	Process time	Water processed		Process rate	
		P-2		P-3		P-4		P-5		P-6		P-7							
		kN/m^2	psi	kN/m^2	psi	kN/m^2	psi	kN/m^2	psi	kN/m^2	psi	kN/m^2	psi	kW	hr	m^3	gal	m^3/hr	gal/hr
Baseline tap water	1	117.2	17	117.2	17	110.3	16	103.4	15	89.6	13	20.7	3	0.322	0.702	0.299	79	0.426	112.5
Wash water	2	151.7	22	144.8	21	137.9	20	137.9	20	117.2	17	6.9	1	0.339	0.900	0.299	79	0.332	87.8
	3	310.3	45	296.5	43	289.6	42	282.7	41	227.5	33	13.8	2	0.510	0.833	0.295	78	0.354	93.6
	4	372.3	54	372.3	54	358.5	52	344.7	50	275.8	40	0	0	0.567	1.067	0.288	76	0.270	71.2
	5	275.8	40	255.1	37	220.6	32	220.6	32	186.2	27	62.1	9	0.536	0.417	0.303	80	0.726	191.8
	6	275.8	40	255.1	37	241.3	35	220.6	32	165.5	24	13.8	2	0.536	0.701	0.307	81	0.437	115.5
	7	275.8	40	255.1	37	241.3	35	220.6	32	137.9	20	0	0	0.555	1.417	0.307	81	0.217	57.2
	8	275.8	40	248.2	36	234.4	34	206.8	30	110.3	16	0	0	0.488	2.330	0.307	81	0.131	34.7
	9	275.8	40	255.1	37	241.3	35	220.6	32	131.0	19	20.7	3	0.515	2.150	0.303	80	0.141	37.2
	10	275.8	40	248.2	36	227.5	33	199.9	29	137.9	20	82.7	12	0.667	0.383	0.326	86	0.850	224.5
	11	275.8	40	241.3	35	220.6	32	199.9	29	110.3	16	55.2	8	0.648	0.483	0.326	85	0.666	176.0
	12	275.8	40	234.4	34	213.7	31	199.9	29	62.1	9	13.8	2	0.587	0.833	0.326	86	0.391	103.2

[a]See figure 1 for pressure measurement location.

TABLE III.- SUMMARY OF REVERSE-OSMOSIS UNIT OPERATIONAL DATA

Test	Test day	Operating pressures obtained from gage[a] –						FM-2 concentrate loop[a]		Pump power	Process time	Water processed		Process rate		Water temperatures obtained from gage[a] –			
		P-8		P-9		P-10										T-3		T-4	
		kN/m²	psi	kN/m²	psi	kN/m²	psi	m³/min	gal/min	kW	hr	m³	gal	m³/hr	gal/hr	K	°F	K	°F
Baseline tap water	1	2861	415	2365	343	21	3	0.0059	1.56	5.25	0.503	0.291	77	0.580	153.1	304	87	301	82
Wash water	2	2758	400	2358	342	21	3	0.0057	1.51	5.40	0.702	0.242	64	0.345	91.2	302	84	299	79
	3	2758	400	2275	330	14	2	0.0175	4.63	5.37	0.783	0.242	64	0.309	81.7	302	83	299	78
	4	2758	400	2241	325	14	2	0.0042	1.10	5.24	0.783	0.242	64	0.309	81.7	301	82	298	77
	5	2758	400	2275	330	21	3	0.0059	1.56	5.36	0.683	0.235	62	0.344	90.8	304	87	302	84
	6	2758	400	2248	326	21	3	0.0042	1.10	5.36	0.750	0.246	65	0.328	86.7	302	83	304	87
	7	2758	400	2262	328	21	3	0.0042	1.10	5.36	0.750	0.238	63	0.318	84.0	301	82	299	79
	8	2758	400	2275	330	21	3	0.0144	3.80	5.38	0.716	0.238	63	0.333	88.0	303	85	300	81
	9	2758	400	2262	328	21	3	0.0159	4.20	5.48	0.733	0.242	64	0.330	87.3	302	83	300	80
	10	2758	400	2262	328	14	2	0.0163	4.30	5.40	0.833	0.261	69	0.313	82.8	301	82	299	78
	11	2758	400	2296	333	14	2	0.0113	3.00	5.48	0.817	0.257	68	0.315	83.2	303	85	300	81
	12	2758	400	2275	330	14	2	0.0058	1.54	5.33	0.917	0.254	67	0.277	73.1	303	85	300	81
Post baseline tap water	12	2758	400	2199	319	0	0	0.0051	1.36	5.37	0.883	0.278	72	0.308	81.5	301	82	299	78

[a]See figure 1 for measurement location.

TABLE IV.- SUMMARY OF COMMODE WATER SUPPLY UNIT DATA

Test	Test day	Volume of flush water treated		Volume of chlorination solution used[a]	Number of flushes	Volume of flush water used	
		m^3	gal	ml		m^3	gal
Baseline tap water	1	0	0	0	18	0.189	50
Wash water	2	0.238	63	118	21	0.231	61
	3	0.238	63	144	21	0.208	55
	4	0.238	63	120	21	0.216	57
	5	0.231	61	118	21	0.220	58
	6	0.242	64	122	21	0.223	59
	7	0.235	62	118	21	0.223	59
	8	0.235	62	118	21	0.227	60
	9	0.238	63	120	20	0.231	61
	10	0.254	67	129	21	0.227	60
	11	0.250	66	128	21	0.220	58
	12	0.246	65	124	21	0.197	52

[a]Water solution of sodium dichloro-s-triazinetrione containing 1000 ppm available chlorine.

TABLE V.- SUMMARY OF WASH WATER COLLECTED

Test	Test day	Volume of shower water collected[a]				Volume of clothes wash water collected[b]				Weight of clothes washed	
		Hot[c]		Cold[d]		Hot[c]		Cold[d]			
		m^3	gal	m^3	gal	m^3	gal	m^3	gal	kg	lb
Baseline tap water[a]	1	-----	---	-----	---	-----	---	-----	---	---	---
Wash water	2	0.0257	6.8	0.0148	3.9	0.0731	19.3	0.2873	75.9	8.44	18.6
	3	0.0257	6.8	0.0110	2.9	0.0693	18.3	0.2805	74.1	9.30	20.5
	4	0.0250	6.6	0.0174	4.6	0.0738	19.5	0.2911	76.9	7.35	16.2
	5	0.0454	12.0	0.0322	8.5	0.1457	38.5	0.1685	44.5	6.35	14.0
	6	0.0450	11.9	0.0231	6.1	0.1166	30.8	0.2392	63.2	7.71	17.0
	7	0.0182	4.8	0.0397	10.5	0.0715	18.9	0.2843	75.1	8.30	18.3
	8	0.0242	6.4	0.0151	4.0	0.0734	19.4	0.2968	78.4	4.54	10.0
	9	0.0197	5.2	0.0269	7.1	0.0719	19.0	0.2866	75.7	8.53	18.8
	10	0.0174	4.6	0.0280	7.4	0.0704	18.6	0.2514	66.4	7.71	17.0
	11	0.0174	4.6	0.0254	6.7	0.0715	18.9	0.2873	75.9	7.39	16.3
	12	0.0273	7.2	0.0288	7.6	0.0723	19.1	0.2881	76.1	6.94	15.3

[a]Daily shower water obtained from one shower bath using an average of 2.73 grams (0.096 oz) of commercial bath soap per shower.

[b]Daily clothes wash water obtained from 2 wash loads using an average of 78.5 grams (0.277 oz) of detergent per wash load.

[c]Hot water temperature averaged 338 K (149° F).

[d]Cold water temperature averaged 286 K (55° F).

[e]Baseline test performed with tap water only. 0.1484 m^3 (39.2 gal) hot water and 0.2585 m^3 (68.3 gal) cold water.

TABLE VI.- SUMMARY OF CHEMICAL AND PHYSICAL WATER DATA FROM BASELINE TEST

(a) Metals

Parameter	U.S. Public Health Standard, ppm	Tap water,[a] ppm	Filtered tap water,[b] ppm	Reverse-osmosis processed tap water,[c] ppm
Arsenic	0.05	<0.01	<0.01	<0.01
Barium	1.0	<1.0	<1.0	<1.0
Boron	None	<1.0	<1.0	<1.0
Cadmium	0.01	<0.01	<0.01	<0.01
Chromium	0.05	<0.05	<0.05	<0.05
Copper	1.0	0.1	0.1	<0.05
Iron	0.3	0.4	0.18	<0.05
Lead	0.05	0.01	0.01	<0.01
Magnesium	None	1.6	1.7	0.2
Manganese	0.05	<0.05	<0.05	<0.05
Mercury	None	<0.001	<0.001	<0.001
Nickel	None	<0.10	<0.10	<0.10
Selenium	0.01	<0.01	<0.01	<0.01
Silver	0.05	<0.05	<0.05	<0.05
Zinc	5.0	0.43	0.30	0.04

(b) Ions

Parameter	U.S. Public Health Standard, ppm	Tap water,[a] ppm	Filtered tap water,[b] ppm	Reverse-osmosis processed tap water,[c] ppm
Ammonium	None	<0.05	0.09	0.12
Calcium	None	24	25	1.0
Chloride	250	15	16	4.7
Chlorine	None	0.15	0.16	<0.05
Cyanide	0.2	<0.02	<0.02	<0.02
Fluoride	1.70	0.92	0.96	0.12
Nitrate and nitrite	45	0.4	0.4	<0.2
Phosphates	None	1.6	1.3	0.3
Potassium	None	1.3	1.2	0.85
Sodium	None	39	37	<10
Sulfate	250	39	37	<10

[a]Sample port 1.
[b]Sample port 3.
[c]Sample port 6.

TABLE VI.- SUMMARY OF CHEMICAL AND PHYSICAL WATER DATA FROM BASELINE TEST – Concluded

(c) Organic data

Parameter	U.S. Public Health Standard, ppm	Tap water,[a] ppm	Filtered tap water,[b] ppm	Reverse-osmosis processed tap water,[c] ppm
Carbon chloroform extractable materials	0.2	30	29	30
Methylene blue active substances	0.5	0.1	0.1	1.0
Phenols	0.001	Analysis not performed		
Total organic carbon	None	<5	<5	<5
Urea	None	<0.05	<0.05	<0.05

(d) Physical data

Parameter	U.S. Public Health Standard, ppm	Tap water,[a] ppm	Filtered tap water,[b] ppm	Reverse-osmosis processed tap water,[c] ppm
Color, $PtCl_6$ units	15	<5	<5	<5
Conductivity micromhos per centimeter	None	180	182	34
Odor threshold number	3	1	1	1
pH units	None	7.2	6.8	6.7
Suspended solids, ppm	None	<100	<100	<100
Total solids, ppm	500	2.39	213	<100
Turbidity, ppm, SiO_2 equivalent	5.0	1.8	0.47	0.10

[a]Sample port 1.
[b]Sample port 3.
[c]Sample port 6.

TABLE VII.- SUMMARY OF CHEMICAL AND PHYSICAL DATA FOR WASH WATER TESTS

(a) Metals

Parameter	U.S. Public Health Standard	Unit	Wash water[a]	Filter processed water[b]	Reverse-osmosis processed water[c]	Percent reduction[d]		
						Filter	Reverse osmosis	Total
Arsenic	0.05	ppm	Not performed		<0.01	(e)	(e)	(e)
Barium	1.0	ppm	<1.0	<1.0	<1.0	(e)	(e)	(e)
Boron	None	ppm	<1.0	<1.0	<1.0	(e)	(e)	(e)
Cadmium	0.01	ppm	<0.01	<0.01	<0.01	(e)	(e)	(e)
Chromium	0.05	ppm	<0.05	<0.05	<0.05	(e)	(e)	(e)
Copper	1.0	ppm	0.11	0.12	<0.05	(e)	66.6	63.6
Iron	0.3	ppm	0.95	0.82	<0.05	13.6	95.1	95.8
Lead	0.05	ppm	0.06	0.06	0.01	(e)	83.3	83.3
Magnesium	None	ppm	1.98	1.93	0.09	2.5	95.3	95.5
Manganese	0.05	ppm	<0.05	<0.05	<0.05	(e)	(e)	(e)
Mercury	None	ppm	<0.001	<0.001	<0.001	(e)	(e)	(e)
Nickel	None	ppm	<0.1	<0.1	<0.1	(e)	(e)	(e)
Selenium	0.01	ppm	Not performed		<0.01	(e)	(e)	(e)
Silver	0.05	ppm	<0.05	<0.05	<0.05	(e)	(e)	(e)
Zinc	5.0	ppm	1.02	0.95	0.06	5.86	98.6	94.1

(b) Ions

Parameter	U.S. Public Health Standard	Unit	Wash water[a]	Filter processed water[b]	Reverse-osmosis processed water[c]	Percent reduction[d]		
						Filter	Reverse osmosis	Total
Ammonium	None	ppm	0.36	0.23	0.06	36.1	73.8	83.3
Calcium	None	ppm	27.9	26.3	0.52	5.7	93.0	98.1
Chloride	250	ppm	27.6	26.1	4.58	5.4	82.4	83.4
Chlorine	None	ppm	<0.05	<0.05	<0.05	(e)	(e)	(e)
Cyanide	0.2	ppm	<0.02	<0.02	<0.02	(e)	(e)	(e)
Fluoride	1.70	ppm	0.90	0.90	0.09	(e)	90.0	90.0
Nitrate and nitrite	45.0	ppm	<0.2	<0.2	<0.2	(e)	(e)	(e)
Phosphates	None	ppm	189.1	170.0	3.96	10.1	97.7	97.9
Potassium	None	ppm	4.0	3.8	0.18	5.0	92.5	97.8
Sodium	None	ppm	112.72	104.09	7.16	7.6	93.1	93.6
Sulfate	250	ppm	104.3	93.9	<10	9.7	90.4	91.4

[a]Sample port 1.

[b]Sample port 3.

[c]Sample port 6.

[d]Based on paired t tests using a 95 percent confidence value.

[e]No significant reduction.

TABLE VII.- SUMMARY OF CHEMICAL AND PHYSICAL DATA FOR WASH WATER TESTS – Concluded

(c) Organic data

Parameter	U.S. Public Health Standard	Unit	Wash water[a]	Filter processed water[b]	Reverse-osmosis processed water[c]	Percent reduction[d]		
						Filter	Reverse osmosis	Total
Carbon chloroform extract	0.2	ppm	22.5	13.9	<5	38.2	71.2	82.2
Methylene blue active substances	0.5	ppm	48.1	40.3	2.4	16.2	94.0	95.0
Phenols	0.001	ppm	Not performed					
Total organic carbon	None	ppm	76.1	49.6	4.8	34.8	90.3	93.6
Urea	None	ppm	6.1	5.7	6.1	(e)	(e)	(e)

(d) Physical data

Parameter	U.S. Public Health Standard	Unit	Wash water[a]	Filter processed water[b]	Reverse-osmosis processed water[c]	Percent reduction[d]		
						Filter	Reverse osmosis	Total
Color	15	$PtCl_6$ units	95.27	70.3	<5	26.2	94.3	95.8
Conductivity	None	Micromhos per centimeter	480	453	39	5.6	91.3	91.8
Odor	3.0	Threshold number	2.8	2.1	1.2	25.0	42.8	57.1
pH	None	pH units	7.4	7.3	7.1	(e)	2.7	4.0
Suspended solids	None	ppm	102	<100	<100	(e)	(e)	(e)
Total solids	500	ppm	701	613	119	12.5	80.5	88.0
Turbidity	5.0	ppm, SiO_2	74.54	41.1	0.45	44.8	98.9	99.4

[a]Sample port 1.
[b]Sample port 3.
[c]Sample port 6.
[d]Based on paired t tests using a 95 percent confidence value.
[e]No significant reduction.

TABLE VIII.- SUMMARY OF MATERIAL REMOVED BY FILTRATION UNIT

Filter size, μm	Weight of material removed		Volume of wash water processed	
	grams	lb	m^3	gal
1	64	0.141	2.29	606
5	109	0.240		
10	46	0.101		
25	47	0.104		
10	32	0.071		

TABLE IX.- SUMMARY OF MICRO-ORGANISM DATA

Micro-organisms	Number of micro-organisms $(\log_{10})$ from sampling port (see fig. 1)										
	1	2	3	4	5	6 (a)	6 (b)	7 (c)	7 (c)	7 (c)	7 (c)
Total counts/ml:											
Baseline (day 1)	0	0	3.64	4.11	3.11	3.23	(d)	4.91	4.46	4.11	3.89
Wash water (days 2 to 12)	6.76	6.54	6.50	6.75	4.71	4.69	3.00	3.77	2.25	1.20	0
Coliforms/100 ml:											
Baseline (day 1)	0	0	0	(d)	1.77	1.49	(d)	0	0	0	0
Wash water (days 2 to 12)	7.71	7.25	7.07	7.25	5.34	5.50	(d)	0	(d)	0	0

[a]Sample taken before chlorination.

[b]Sample taken 1 hour after chlorination.

[c]Hourly samples.

[d]Analyses not performed.

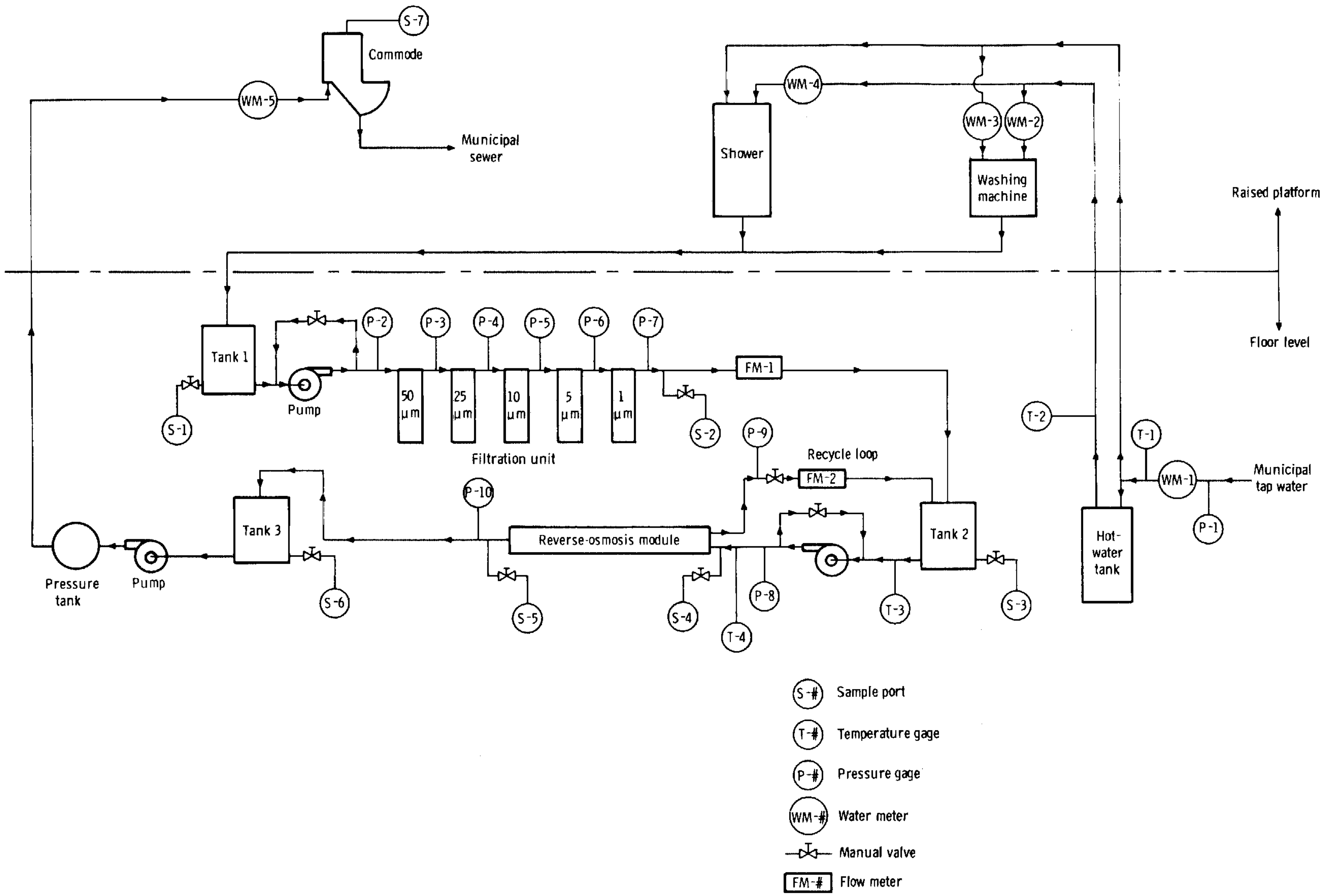

Figure 1.- Schematic drawing of test setup.

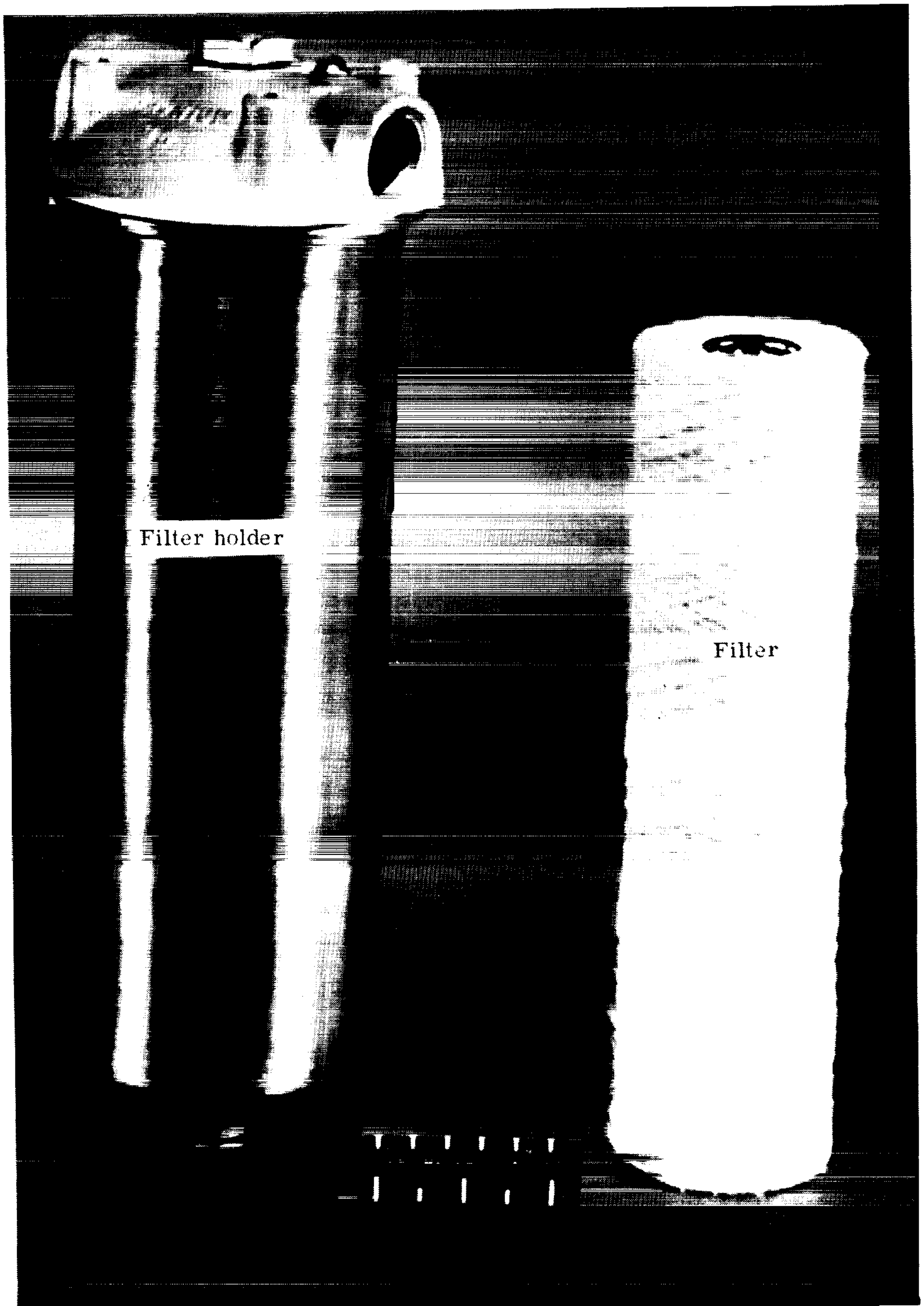

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Figure 2.- Particulate filter and holder.

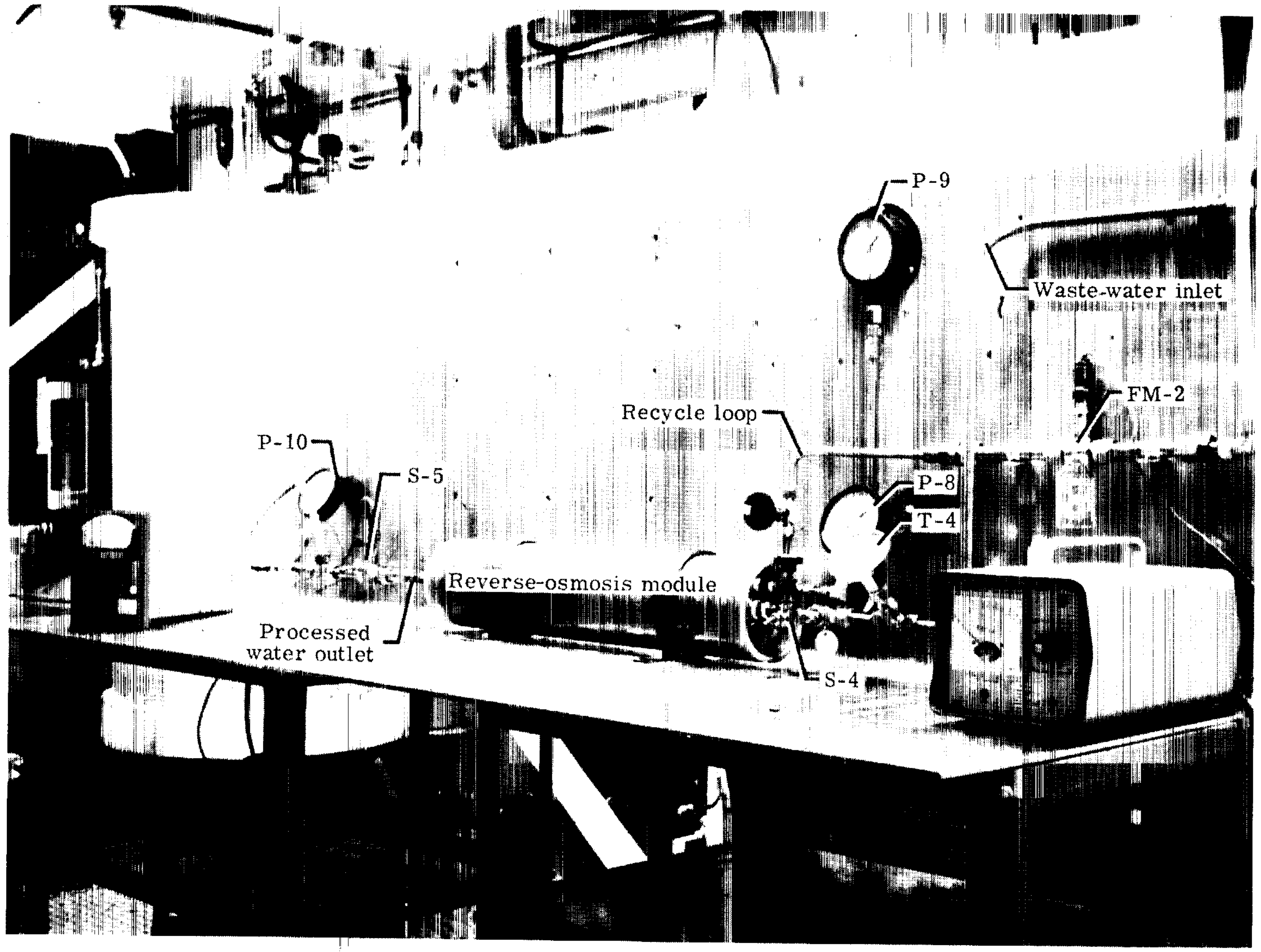

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Figure 3.- Reverse-osmosis subsystem.