MASTER

(Final Revised Version)

ADP-2476

REVERSE OSMOSIS PILOT PLANT STUDIES
FOR THE PURIFICATION AND REUSE
OF EFFLUENT FROM A SANITARY
WASTE TREATMENT PLANT

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ABSTRACT

A description of the Rocky Flats reverse osmosis pilot plant will be given, along with some of the data acquired from those operations. A brief description of the equipment recommended for use in the recycling plant is also included.

INTRODUCTION

Rocky Flats is a nuclear weapons facility located in Colorado, some sixteen air miles northwest of Denver.

The plant is owned by the United States government and is part of the Energy Research and Development Administration's Albuquerque Operations Office. Rockwell International is the operating contractor.

In recent years, the Denver urban sprawl has reached to within only a few miles of the Rocky Flats reservation. The City of Broomfield is within three miles of the reservation, and the surface water storage for Broomfield is fed partly by two creeks which cross the Rocky Flats reservation. In the 20 plus years that the Rocky Flats plant has been in operation, there have been minor releases of radioactivity and chemical contamination.

In late 1969 the Rocky Flats management first began to look at the possibility of zero discharge of pollutants and complete water recycle. In the years since, four very good and valid reasons why the Rocky Flats plant should reach the goal of zero discharge have come to the fore. Probably, the most important reason was a commitment made by the Rocky Flats management and by the U.S. Atomic Energy Commission, the predecessor of ERDA, to the

Governor of the State of Colorado, to the State Health Department, and to the City of Broomfield. That commitment was that the Rocky Flats plant would reach a goal of zero discharge of all aqueous waste. It has always been the policy of the Rocky Flats plant that the effluent leaving the plant would contain the lowest practical limits of contaminants possible for the technology and funding available.

In addition, zero discharge and complete water recycle will further reduce the remote possibility of any accidental release of contamination, chemical or radiological. It will also permit the plant to accomplish the goal of zero discharge of aqueous pollutants by 1985 which has been set forth in the Water Pollution Control Act of 1972, and we will be conserving a natural resource, water, which in our semi-arid region may become a very precious commodity in the not too distant future.

When the Rocky Flats management began to look at the possibility of complete containment of all aqueous wastes, the water system at the Rocky Flats plant, as constituted in 1969, is shown in Figure 1.

Rocky Flats purchases, then as now, 10 and one half million gallons of water per month from the Denver Water Board. This water is treated, using standard water treatment methods, to bring the water up to U.S. Public Health standards for drinking water. The treated water from the water treatment plant was used as process water, make-up water for the steam plant, cooling water in the cooling

FIGURE 1

WATER USAGE AND DISPOSAL - 1969

VOLUMES: X 1000 GALLONS PER MONTH

towers and air washers, and for potable uses. The waste water from these operations and uses was discharged into each of the three such drainages that cross the plantsite. The backwash water from the water treatment plant was discharged into Woman Creek, the effluent from the sanitary waste treatment plant which contained some process waste water was released to South Walnut Creek, and the cooling tower blow-down waters were discharged in North Walnut Creek, South Walnut Creek, and Woman Creek.

In the six years since 1969, Rocky Flats has begun the process of "buttoning-up." Figure 2 shows the present day water usage and disposal. Today, the only discharge of waste water to a creek drainage is through the sanitary waste treatment plant. The backwash water from the water treatment plant goes to settling ponds, and the supernate is returned to the raw water system.

The process waste waters which once were fed into the sanitary waste system now go to holding ponds and will be processed at a later date. All cooling tower blowdown water is fed into the sanitary waste system and is discharged along with the other effluent from the sanitary waste treatment plant.

FIGURE 2

PRESENT WATER USAGE AND DISPOSAL

VOLUMES: X 1000 GALLONS/MONTH

In 1971 it was decided that all process waste waters generated on the plant site, and this included laundry water, would be sent to a new process waste treatment plant. This treatment would include evaporation and spray drying. The distillate would be collected and recycled back into the plant.

There remains only one waste stream to recycle to completely "button-up" the Rocky Flats plant, and have a zero discharge of all aqueous pollutants, the effluent from the sanitary waste treatment plant.

INVOLVEMENT OF RESEARCH AND DEVELOPMENT

Research and Development first became involved in water recycle approximately five years ago. We focused our attention on the cooling tower blowdown water and on the sanitary waste stream.

When we began to look at the various technology available for the purification and recycling of our waste water, we did not consider evaporation. The reasons for this decision were that we did not have, nor would we have, an evaporator large enough to handle these large volumes, and also that evaporation is a high energy consumer.

The technology that we considered are shown in Table I.

Ion Exchange - It was eliminated because of the high cost of regeneration and there would still be large volumes of waste solutions that had to be disposed of.

Freeze-Crystallization is one of the newer technology. However, it has a couple of major disadvantages. These are: (1) it consumes large quantities of electrical energy; (2) it requires a feed water containing 2,000 milligrams per litre or more of total dissolved solids to operate at maximum efficiency; and (3) the product water from this type of operation would contain approximately 500 milligrams per litre of total dissolved solids. Our feed water will range from 400 to 550 milligrams per litre of total dissolved solids.

Ultrafiltration was eliminated because it does not remove dissolved solids of low molecular weight. It does an excellent job of improving the clarity of the water. This has been well demonstrated by the pilot plant on top of Pikes Peak near Colorado Springs.

Electrodialysis was eliminated because it requires a feed water containing a minimum concentration of 3,000 milligrams per litre of total dissolved solids to operate

TABLE I

Technology Considered
for Water Purification

1. Ion Exchange
2. Freeze Crystallization
3. Ultrafiltration
4. Electrodialysis
5. Reverse osmosis

properly. If lower concentrations of total dissolved solids in the feed water are used, high resistances are apt to be encountered in some of the cell pairs. This technology is capable of producing a thousand gallons of product water cheaper than any of the technology that were considered.

That left reverse osmosis. These operating costs appeared to be moderate; energy consumption appeared to also be moderate; the pretreatment required was no more than any of the other technology except the freeze-crystallization where the pretreatment is less; and if designed properly, a minimum volume of brine would be produced by a reverse osmosis unit.

REVERSE OSMOSIS PILOT PLANT

Four years ago, when the laboratory studies were completed, the decision was made to pilot a reverse osmosis unit. It was also decided to locate the pilot operations in a truck trailer because, at that time, we needed that mobility. In the three years that the pilot plant has been operating, we have operated using secondary treated sanitary effluent, cooling tower blowdown waters. For the past two years, pilot operations have been located at the sanitary waste treatment plant using these effluent waters as feed.

The reverse osmosis pilot plant had three goals, and they were: (1) to evaluate and recommend the necessary pretreatment equipment required in a reverse osmosis recycling plant; (2) obtain a product water containing less than 100 milligrams per litre of total dissolved solids; and (3) to keep the volume of brine to less than 10,000 gallons per day at a maximum feed volume of 450,000 gallons per day. The need for a product water containing 100 milligrams per litre or less of total dissolved solids was a standard set by our Utilities Department. The goal to keep the volume of brine at less than 10,000 gallons per day was to keep the loading on the new process waste treatment evaporator to a minimum.

It was evident that if we were to accomplish the third goal a brine concentrator of some sort would be required. For this, we have settled on a secondary reverse osmosis unit.

The layout of the primary reverse osmosis pilot plant is shown in Figure 3. The influent which is approximately 20 gallons per minute passes through the pretreatment equipment. This pretreatment can include sand filtration, a 5 micron high pressure bag filter, water conditioning,

FIGURE 3
REVERSE OSMOSIS PILOT PLANT
(PRIMARY UNIT)

1. PRETREATMENT
2. FEED WATER TANKS
3. CHEMICAL TREATMENT AND
FINAL FILTRATION
4. REVERSE OSMOSIS UNIT - 25,200 GPD
5. PRODUCT WATER TANK

carbon filtration, a diatomaceous earth filter, and a preheater. Any one piece of the pretreatment equipment, or all of the pretreatment equipment, can be bypassed, if desired, except for the sand filter. The pretreated influent is discharged into the feed tanks and is then pumped through the chemical treatment area. The chemical treatment can include pH control, calcium control using hexametaphosphate, chlorine addition, or chlorine destruction. The influent passes through a final filter which is a one micron CUNO type filter, and then enters the reverse osmosis unit. At the present time, we are operating with cellulose triacetate hollow fiber membranes and are producing approximately 17.5 gallons per minute of product water and 2.2 gallons per minute of brine. This is a water recovery of 89 percent.

Figure 4 shows the layout of the secondary unit. The brine solution from the primary unit is discharged into a surge tank and is pumped from there into the secondary feed tanks. The secondary feed is pumped from the feed tanks through a chemical treatment area which includes the addition of chlorine and a solution of "dispersant." The treated feed passes through a 25 micron filter into a spiral wound cellulose acetate reverse osmosis unit. We are producing 2.4 gallons per minute of secondary

FIGURE 4

REVERSE OSMOSIS PILOT PLANT
(SECONDARY UNIT)

1. SURGE TANK
2. SECONDARY FEED WATER TANKS
3. CHEMICAL ADDITIONS AND
FINAL FILTRATION
4. SECONDARY REVERSE OSMOSIS
UNIT - 3750 GPD
5. SECONDARY PRODUCT WATER TANK
6. PROGRAMMABLE LOGIC CONTROLLER
AND PROGRAMMABLE CALCULATOR

product water and 0.2 gallons per minute of secondary brine. This is a water recovery of 92 percent which produces an overall water recovery of 98+ percent.

The operation is under the control of a programmable logic controller, using liquid level probes, timers, temperature controls, and chlorine controls. Some of the pilot plant valving is also under the control of the PLC. We have been attempting to use a programmable calculator for data acquisition and as a back-up system for the controller. To date, this has not been successful.

In addition to evaluating the cellulose triacetate membranes, polyamide hollow fiber membranes have also been evaluated in the primary reverse osmosis unit. Table II shows the advantages of the cellulose triacetate membranes over the polyamide membranes.

Lower operating pressures - The operating pressures of the reverse osmosis system have been 110 to 120 pounds less using the cellulose triacetate membranes than polyamide membranes at the same water recoveries.

Higher rejection rates - The rejection rates of the cellulose triacetate membranes have averaged better than 96 percent; whereas, the rejection rates of the polyamide

TABLE II

Advantages of Cellulose Triacetate Membranes
over Polyamide Membranes

1. Lower operating pressures
2. Higher rejection rates
3. Higher quality of product water
4. Higher water recoveries
5. Lower inorganic scaling
6. No bacterial fouling

membranes averaged about 92 percent. The rejection rates were obtained at the same water recoveries.

Higher quality of product water - The quality of the product water from the cellulose triacetate permeators was consistently better than from the polyamide permeators. The quality of product water when using polyamide membranes ranged from 25 to 35 milligrams per litre of total dissolved solids at water recoveries of less than 80 percent and between 30 and 40 milligrams per litre of total dissolved solids at water recoveries greater than 80 percent. When using the cellulose triacetate membranes, the quality of the product water was 20 to 30 milligrams per litre of total dissolved solids for water recoveries of 85 to 90 percent and 15 to 25 milligrams per litre for water recoveries ranging from 80 to 85 percent.

High water recoveries - We have been able to obtain water recoveries of 89 to 90 percent without using high operating pressures. The operating pressures have been maintained at about 245 pounds. The best water recoveries using the polyamide membranes at reasonable pressures--300 to 310 pounds--was 83 to 84 percent.

Lower inorganic scaling - During our operations at the sanitary waste treatment plant, there have been upsets

caused by various conditions. When there was an upset, the pilot operations took the full brunt of the upset. When operating with the polyamide membranes, an upset would normally mean that we had to close down the pilot operations and go through a complete cleaning. Very often, we would have to go through one or more of the individual cleanings two or three times. However, we have not had to close down the pilot operations because of an upset at the sanitary treatment plant since changing to the cellulose triacetate membranes. We have done one minor cleaning of the cellulose triacetate membranes since installing them early last May.

No bacterial fouling - The polyamide membranes will be destroyed if they come into contact with chlorine. Therefore, when we were using the polyamide membranes, the feed water was obtained before the effluent was chlorinated. This resulted in the fouling of the membranes with bacteria. The membranes had to be cleaned about every 48 to 72 hours of operation to remove the buildup of bacteria. This was done by adding about 12 ounces of BIZ to our feed water tank. We have had no problems with bacteria fouling since switching to the cellulose triacetate membranes because their recommended tolerance for chlorine is one milligram per litre of free chlorine. We have been

operating using the chlorinated effluent from the sanitary waste treatment plant, and this contains free chlorine in the range of 0.2 to 0.5 milligrams per litre.

An additional advantage is that the flux of the cellulose triacetate membranes is three times greater than the flux of the polyamide membranes.

Table III shows the advantages that polyamide membranes have over the cellulose triacetate membranes.

Less effect by temperature change - Much better temperature control must be exercised when using cellulose triacetate membranes than when using polyamide membranes if there is to be any control of the product water flow. A slight temperature change--a degree or two C--would cause a change in the product flow when using cellulose acetate membranes.

Silica can be removed - To remove silica scaling from the surface of the membranes, a solution of sodium hydroxide at a pH of 11 must be used. The polyamide membranes can withstand a solution at this high pH, but the cellulose triacetate membranes cannot. It is, therefore, essential that there is no colloidal silica in the feed water, and that the concentration of the dissolved silica is low.

TABLE III

Advantages of Polyamide Membranes
over Cellulose Triacetate Membranes

1. Less effect by temperature change
2. Silica scaling can be removed

Tables IV through VIII show some of the results obtained from the reverse osmosis pilot plant operations. These data have been collected during the past 12 months of operation.

The analyses of our primary product water for fecal coliform, total coliform, and total bacteria have all been negative.

Finally, the reverse osmosis recycling plant. The pretreatment in the recycling plant will include sand filtration, water conditioning, a diatomaceous earth filter, preheating, pH adjustments, and chlorine additions.

Sand filters - These will be used to remove the larger suspended material that may be blown or thrown into the feed pond.

The water conditioning will be used to remove the calcium that naturally occurs in our waters. The calcium concentration range is between 20 and 30 milligrams per litre. There is also a sufficiently high concentration of sulfate in our waste water that without the removal of the calcium, gypsum would precipitate before we obtained our desired 50-fold concentration of the total dissolved solids.

TABLE IV
Concentration of Impurities
in Feed for the Primary Reverse Osmosis Unit

	Range, mg/l	Average, mg/l
Aluminum	<0.5	<0.5
Bicarbonate	6-65	33
Calcium	0.1-0.6	0.4
Chloride	30-130	70
Chromium, total	<0.1	<0.1
Copper	<0.1	<0.1
Fluoride	0.3-0.5	0.4
Iron, total	0.1-0.2	0.1
Magnesium	0.1-0.7	0.3
Manganese	<0.1	<0.1
Nickel	<0.1	<0.1
Nitrate	25-40	32
Phosphate	0.8-3.0	2.0
Potassium	2-42	12
Silicon, as Si	5-10	6
Sodium	104-200	155
Sulfate	131-349	224
Zinc	0.1-0.3	0.2
Total Dissolved Solids	340-630	475
Turbidity, as JTU	0.18-0.57	0.31
pH	3.5-6.0	

TABLE V
Concentration of Impurities
in Product Water from the Primary Reverse Osmosis Unit

	Range, mg/l	Average, mg/l
Aluminum	<0.5	<0.5
Bicarbonate	<1-14	7
Calcium	<0.1-0.5	0.2
Chloride	<1-8	3
Chromium, total	<0.1	<0.1
Copper	<0.1	<0.1
Fluoride	0.1-0.5	0.2
Iron, total	<0.1-0.1	0.1
Magnesium	<0.1-0.1	0.1
Manganese	<0.1	<0.1
Nickel	<0.1	<0.1
Nitrate	3-8	5
Phosphate	0.02-0.31	0.08
Potassium	<0.5-1.6	0.6
Silicon, as Si	<1-2	1
Sodium	5-12	8
Sulfate	<1-5	1
Zinc	<0.1-0.2	0.1
Total Dissolved Solids	5-40	24
Turbidity, as JTU	0.05-0.23	0.10
pH	4.5-5.5	

TABLE VI

Concentration of Impurities
in Brine from the Primary Reverse Osmosis Unit
(Feed for the Secondary Reverse Osmosis Unit)

	Range, mg/l	Average, mg/l
Aluminum	<0.5-1.7	0.8
Bicarbonate	1-40	27
Calcium	0.3-1.6	0.7
Chloride	380-640	505
Chromium, total	<0.1-0.1	0.1
Copper	<0.1-0.7	0.4
Fluoride	0.3-1.4	1.0
Iron, total	0.3-1.0	0.6
Magnesium	0.2-0.4	0.3
Manganese	<0.1	<0.1
Nickel	<0.1	<0.1
Nitrate	150-270	210
Phosphate	4-37	13
Potassium	20-41	27
Silicon, as Si	40-52	44
Sodium	750-1100	900
Sulfate	1040-1720	1410
Zinc	0.5-0.8	0.6
Total Dissolved Solids	3520-4590	3920
Turbidity, as JTU	0.48-1.20	0.78
pH	3.0-6.0	

TABLE VII

Concentration of Impurities
in Product Water
from the Secondary Reverse Osmosis Unit

	Range, mg/l	Average, mg/l
Aluminum	<0.5	<0.5
Bicarbonate	4-47	20
Calcium	<0.1-0.9	0.5
Chloride	200-415	290
Chromium, total	<0.1	<0.1
Copper	<0.1	<0.1
Fluoride	0.2-0.6	0.4
Iron, total	0.1-0.3	0.2
Magnesium	<0.1-0.3	0.2
Manganese	<0.1	<0.1
Nickel	<0.1	<0.1
Nitrate	10-75	42
Phosphate	0.2-1.0	0.6
Potassium	8-12	11
Silicon, as Si	12-24	17
Sodium	210-300	250
Sulfate	20-100	56
Zinc	<0.1-0.6	0.3
Total Dissolved Solids	510-720	650
Turbidity, as JTU	0.10-0.20	0.15
pH	4.5-5.5	

TABLE VIII

Concentration of Impurities
in Brine
from the Secondary Reverse Osmosis Unit

	Range, mg/l	Average, mg/l
Aluminum	0.7-2.0	1.4
Bicarbonate	160-1100	580
Calcium	3-48	32
Chloride	1400-2900	1990
Chromium, total	<0.1-0.1	0.1
Copper	<0.1-5.7	2.5
Fluoride	0.8-8.8	3.8
Iron, total	2.0-8.4	4.4
Magnesium	4-12	8
Manganese	<0.1-0.1	0.1
Nickel	0.2-0.6	0.4
Nitrate	100-430	240
Phosphate	41-180	97
Potassium	160-220	190
Silicon, as Si	90-210	160
Sodium	4600-6800	5400
Sulfate	6600-9700	8740
Zinc	9-32	15
Total Dissolved Solids	16,900-23,000	19,700
Turbidity, as JT _u	1.1-4.0	2.8
pH	3.0-6.0	

The diatomaceous earth filters will remove any silt or colloidal material that may be blown into the feed pond. The D.E. filter should be capable of removing any particle larger than 0.5 micron.

The preheater will bring the temperature of the feed water to 25°C which is the recommended operating temperature. A lowering of the temperature by 1°C will reduce the volume of product water by about 3 percent.

The pH of the present feed water normally is in the range of 6.5 to 7.0. Our studies have shown that a better operating pH range would be 4.5 to 5.5. If we operate at a pH of 6.0 or above, the volume of the product water produced will be reduced, a loss of flux. This is apparently due to carbonates in the feed water scaling the membranes, and by reducing the pH we destroy the carbonates before they can cause any scaling.

The chlorine addition is to prevent any bacterial growth which could destroy the reverse osmosis membranes.

Cellulose triacetate hollow fiber membranes will be used in the primary reverse osmosis unit, and cellulose acetate spiral wound membranes will be used in the secondary reverse osmosis unit with a 90 percent water recovery from the primary unit and from the secondary unit.

With this type of plant, our pilot plant studies have shown that we can obtain a product water which will contain less than 100 milligrams per litre of total dissolved solids and that the flow of brine to the process waste treatment evaporator will be no greater than 2 percent of the feed stream going to the reverse osmosis recycling plant. The reverse osmosis recycling plant will be controlled by a programmable logic controller.

This reverse osmosis plant is presently in the design stages.