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SHOWER WATER RECYCLE IV. REVERSE OSMOSIS STUDIES

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The U.S. Army Biomedical Research and Development Laboratory has investigated the use of reverse osmosis (RO) for treatment of shower wastewater for recycle. The synthetic challenge (feed) water contained 17 to 100 mg/L of total organic carbon (TOC) as soap; permeate (product) water is of excellent quality in terms of TOC, chemical oxygen demand, turbidity, and conductivity. Most removal of organic materials was accomplished by the prefilters rather than the RO module. Challenge water was reduced to 20 percent of its original volume with no evidence of flow restriction through the RO module. Heat buildup in the course of batch operation is a serious drawback to use of RO for shower water treatment; recommended temperature limits for the RO module were exceeded on several occasions.

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PREFACE

This project was supported in part by the U.S. Army Quartermaster Center and School Directorate of Combat Development, Fort Lee, VA, under MIPR 710-91. Project officers were MAJ Bobby R. Templin, MS, and Mr. Joseph Aldrich.

INTRODUCTION

This U.S. Army Biomedical Research and Development Laboratory (USABRDL) study addresses one of several technologies being evaluated to treat shower wastewater for possible recycle. The Army and others have recognized that shower facilities for personnel may impose the greatest demand for high quality nonpotable water in the field. A substantial reduction in demand could be realized through development of this type of technology, and the concomitant reduction in wastewater would diminish the problem of insect vector breeding in discharge ponds. Earlier reports have addressed the characteristics of shower water and the treatment efficacy of flocculation[1] and microfiltration[2] as well as the health concerns for shower water reuse.[3]

For several reasons, USABRDL has considered reverse osmosis (RO) to be a marginally suitable technology for treatment of shower wastewater for recycle although product quality would be expected to be very high. The major problem is that RO treats only a portion (typically less than half) of the feed water, rejecting the rest. This makes the technology much less suitable for batch operation than for continuous operation, such as purification of seawater. To achieve acceptable recovery, i.e., 80 percent or better, of treated water in a batch process, the reject stream must be reprocessed continuously, and the RO membrane is eventually challenged with a wastewater concentrated at least five-fold. Early membrane fouling is anticipated. However, the ready availability of the 600 gph reverse osmosis water purification unit (ROWPU) to U.S. Army field units encourages evaluation of this technology.[4] Lozier and Kuepper have discussed options for use of ROWPU for treatment of shower and laundry wastewaters.[5]

MATERIALS AND METHODS

TEST STAND. The RO test stand (Jack Holz and Associates, Inc., Fredericksburg, VA) utilized a single 6-in diameter, 3-ft UOP Fluid Systems thin film composite 1501 RO module. Prefiltration was by means of seven 0.5-m spiral wound polypropylene cartridges of 5 μm nominal pore size (Delta Pure DW 5-03-20-1, Ashland, VA) in a stainless steel housing (Filterite Model 910608-000, Timonium, MD). A 500-gal (1,890 L) feed tank was equipped with a submerged pump for mixing and a tap water heat exchanger.

CHALLENGE WATER. Challenge water was prepared by dissolving 75.7 g (Runs 1 and 3) or 37.85 g (Run 2) of Ivory[R] soap, pulverized as received, in 400 gal (1,514 L) of Fort Detrick tap water that had been deionized by RO. This was intended to provide a final concentration of 50 mg/L (Runs 1 and 3) or 25 mg/L (Run 2) of soap, corresponding to a total organic carbon (TOC) of ca. 34 or 17 mg/L and a COD of ca. 130 or 65 mg/L. [The measured values for the initial feed water (Table 3) were substantially lower, probably because the RO module failed shortly after the beginning of Run 3. The module and prefilters were replaced and the run was restarted; analytical data refer to the restarted run.] For Run 4, 238 g of pulverized soap was dissolved in hot water and added to 430 gal (1,628 L) of tap water to give a calculated TOC of 100 mg/L. Ivory[R] soap was determined to incorporate about 2 percent water as received. The pH was not adjusted for any run.

TEST PROCEDURE. Initially, the RO permeate (product) and reject (brine) streams were returned to the challenge water supply (feed tank) so that the test unit was subjected to a constant challenge. After a designated period (1-4 hr), the permeate line was discharged to waste; and the feed water was allowed to concentrate until the end of the experiment. New RO modules were installed for Runs 2 and 3; the module used in Run 1 had been used previously for water soluble salts. Fresh prefilters were used for Runs 1, 3, and 4.

ANALYTICAL PROCEDURES. Total organic carbon and COD analyses were performed by Gascoyne Laboratories, Inc., Baltimore MD. Samples were not preserved before analysis because addition of sulfuric acid caused irreversible precipitation of the free fatty acids. Turbidity was measured by means of a Model 2100A Turbidimeter (Hach Chemical Co., Ames, IA). Conductivity measurements were made using a Prest-Tek DP-03 conductivity meter (Devon Products Corp., Los Angeles, CA). Measurements of pH were made using an Extech Digital pH Meter 609 (Boston, MA). For Runs 1 and 3, all measurements were repeated at 4 hr (i.e., before and after removal of the permeate hose from the feed tank) thereby providing a measurement of quality control.

RESULTS AND DISCUSSION

Results for the four test runs are summarized in Tables 1 through 4. Microfiltration experiments had indicated serious membrane fouling by calcium soaps when a hard tap water was used to prepare the challenge water.[2] Because it seemed certain that RO membranes would be even more subject to fouling, we chose to use deionized water (prepared with the same RO unit) in the first three RO tests; and the results of these studies are applicable to ROWPU water (or RO recycled shower water) only. In the first run, restriction of permeate (product) flow from a challenge (feed) water containing 50 mg/L of soap was noticeable after 30 min. of operation and exceeded 50 percent after 4 hr at a constant challenge (Table 1). Permeate flow was reduced even further when the feed water was allowed to concentrate. For the second run, the initial soap concentration was reduced to 25 mg/L. No evidence of flow restriction was observed during 2 hr of operation after which the high-pressure pump failed and the experiment was terminated (Table 2). During both runs, the feed water turbidity was sharply reduced throughout the course of the experiment, indicating that soap was being taken up from the feed water b either the RO module or the prefilters.

There was no restriction of flow observed for the third run during either the 4 hr of constant challenge or the 30 min of concentration (Table 3). Nonetheless, feed turbidity, TOC, and COD all fell markedly during the first 2 hr, remaining essentially constant thereafter. Because this run was performed in midsummer (rather than February and March as in the case of the first two runs), the tap water heat exchanger was inadequate to control the feed water temperature. On two occasions the RO unit shut itself down (due to heat transfer from the high pressure pump) and had to be reprogrammed for a higher temperature in order to complete the experiment. However, product TOC, COD, turbidity, and conductivity were all very low indicating that membrane integrity had not been compromised by the higher temperature.

TABLE 1. RUN 1

Sample and time, min	pH	Conductivity μmho	Pressure psi	Vol gal	Flow gpm	Turbidity NTU	Temp. ^oF
0 Feed	6.20	209.0	830	400	20.0	32.00	70
0 Prod	7.01	15.4	850		3.0	0.40	
10 Feed			840	400	20.0		
10 Prod			860		2.2		
30 Feed			860	400	20.0		
30 Prod			880		1.8		
45 Feed			860	400	20.0		
45 Prod			880		1.7		
60 Feed	6.35	207.0	860	400	20.0	24.00	72
60 Prod	6.90	7.7	870		1.7	0.38	
90 Feed			860	400	20.0		
90 Prod			875		1.6		
120 Feed	6.40	207.0	860	400	20.0	19.00	80
120 Prod	7.00	10.2	870		1.6	0.39	
150 Feed			860	400	20.0		
150 Prod			875		1.5		
180 Feed	6.40	210.0	860	400	20.0	10.00	82
180 Prod	7.02	18.7	870		1.5	0.22	
210 Feed			860	400	20.0		
210 Prod			875		1.4		
240 Feed	6.41	213.0	860	400	20.0	7.40	86
240 Prod	6.97	6.7	875		1.4	0.22	
240 Feed	6.41	213.0	860	400	20.0	7.40	86
240 Prod	6.98	5.9	875		1.4	0.22	
270 Feed	6.49	244.0	860	340	20.0	7.50	88
270 Prod	7.07	6.7	875		1.4	0.22	
315 Feed	6.51	288.0	860	270	20.0	7.50	90
315 Prod	7.16	7.[illegible]	875		1.3	0.26	
[illegible]	6.52	357.0	860	200	20.0	7.00	93
360 Prod	7.2[illegible]	8.2	875		1.1	0.27	

The fourth run represented the most serious challenge (Table 4). A soap concentration equivalent to 100 mg/L as TOC in hard (ca. 150 mg/L as $CaCO_3$) tap water was used, the heat exchanger was disconnected and the temperature limit switch was inactivated. The RO module from Run 3 was used, but all new prefilters were installed. Feed water turbidity fell rapidly as in Run 3, but no restriction of flow was observed even as recovery exceeded 80 percent. During the second half of the run, the feed water temperature was well above the recommended limit of 100^0 F for sustained use;[6] but conductivity reduction exceeded 99 percent.

TABLE 2. RUN 2

Sample and time, min	pH	Conductivity μmho	Pressure psi	Vol gal	Flow gpm	Turbidity NTU	Temp. °F
0 Feed	6.26	66	600	400	19	12.00	64
0 Prod		3	620		3	0.25	
15 Feed	6.31	64	600	400	19	13.00	
15 Prod		3	600		3	0.25	
30 Feed	6.36	62	620	400	19	11.00	
30 Prod		1	640		3	0.20	
45 Feed	6.36	52	620	400	19	12.00	
45 Prod		1	640		3	0.20	
60 Feed	6.38	48	620	400	19	5.40	66
60 Prod		1	640		3	0.20	
90 Feed	6.42	48	630	400	19	2.00	
90 Prod		1	640		3	0.10	
120 Feed	6.46	44	630	400	19	1.50	70
120 Prod		1	640		3	0.26	
120 Feed[a]	6.53	50	720	400	19	11.00	
120 Prod[b]		1	740	400	3	.20	

a. 37.85 mg/L soap added at this point.
b. System failure occurred shortly following collection of this sample.

There is no question that RO is capable of generating a high quality of water from shower wastewater. Recycled water standards (Table 4) are readily met; indeed, conductivity, organic content, and turbidity levels suggest that the permeate could be acceptable for potable use (Table 5). [Conductivity of 10 μmho corresponds to a total dissolved solids level of ca. 7 mg/L.] The suitability of RO in general, or ROWPU in particular, for treating shower wastewater will depend not on water quality but on water recovery and on the lifetimes of system components. It is apparent from all four runs reported here that most of the organic material is removed by mechanisms other than RO. Early fouling can be anticipated if any substantial part of this removal results from deposition of soap onto the RO membrane; this may have caused the progressive restriction of permeate flow observed in Run 1 (Table 1), but no subsequent run exhibited this effect. The data are not unequivocal although limited brine side testing during Run 3 does not indicate removal of organic material by the RO module.

TABLE 3. RUN 3

Sample and time, min		pH	Conductivity µmho	Pressure psi	Vol gal	Flow gpm	Turbidity NTU	TOC mg/L	COD mg/L
0	Feed	7.71	570	760	400	18.0	55	16	85
0	Prod		9	780		3.0	0.2	2	20
15	Feed	7.74	570	720	400	18.0	28	12	62
15	Prod		4	740		3.0	0.2	<1	13
15	Brine							17	64
30	Feed	7.75	580	700	400	18.0	25	11	67
30	Prod		4	720		3.0	0.38	<1	<1
30	Brine							18	63
45	Feed	7.75	610	680	400	18.0	20	10	53
45	Prod		4	690		3.0	0.32	<1	5
60	Feed	7.75	600	680	400	18.0	19	11	59
60	Prod		4	690		3.0	0.23	<1	5
90	Feed			640	400	18.0			
90	Prod			660		3.0			
120	Feed	7.72	680	640	400	18.0	7	10	30
120	Prod		6	650		3.0	0.24	<1	<1
150	Feed			640	400	18.0			
150	Prod			650		3.0			
180	Feed[a]	7.72	620	605	400	18.0	7	9	14
180	Prod		6	620		3.0	0.26	<1	<1
210	Feed[b]			600	400	18.0			
210	Prod			620		3.0			
240	Feed	7.72	640	600	400	18.0	5	9	25
240	Prod		7	610		3.0	0.2	<1	<1
240	Feed[c]	7.72	640	600	400	18.0	5	8	20
240	Prod		7	610		3.0	0.2	<1	<1
270	Feed	7.72	850	680	200	18.3	4	10	41
270	Prod		6	700		3.0	0.2	<1	<1

a. Temperature limit reset to 96°F.
b. Temperature limit reset to 98°F.
c. Permeate hose removed from feed tank.

One would expect some turbidity to be removed by the prefilters alone. The configuration of the USABRDL test stand did not allow for sampling between the prefilters and the RO module; however, Figure 1 compares observed turbidity removal from the feed tank during Run 3 with calculated turbidity decay assuming 100 percent removal in the prefilters. It is seen that removal of turbidity by the prefilters is incomplete and that the RO module is exposed to turbid water throughout the run. On the other hand, the same treatment of data from Run 4 shows that theoretical turbidity removal is slightly exceeded (Figure 2). (As expected for hard water, a heavy soap scum formed, and an unquantifiable amount adhered to the sides of the feed tank.) In any event, it is clear that the bulk of organic material is removed by the prefilters. Visual inspection of the prefilters after Runs 3 and 4 revealed no obvious fouling. Estimation of the mean length of run before RO module fouling and the effect of prefilter replacement thereon await further testing.

Figure 1. Removal of Turbidity from Feed Water, Run 3

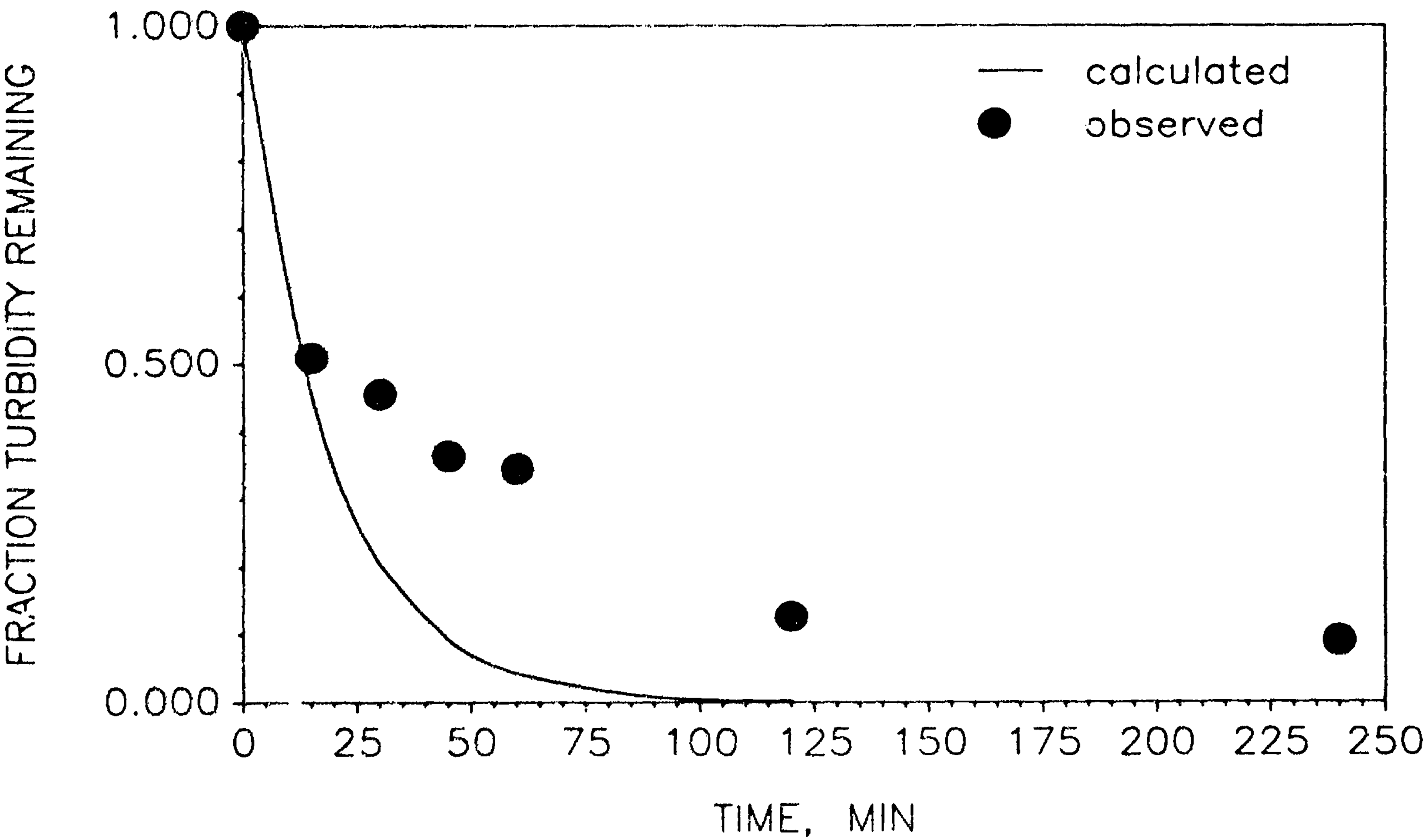

Figure 2. Removal of Turbidity from Feed Water, Run 4

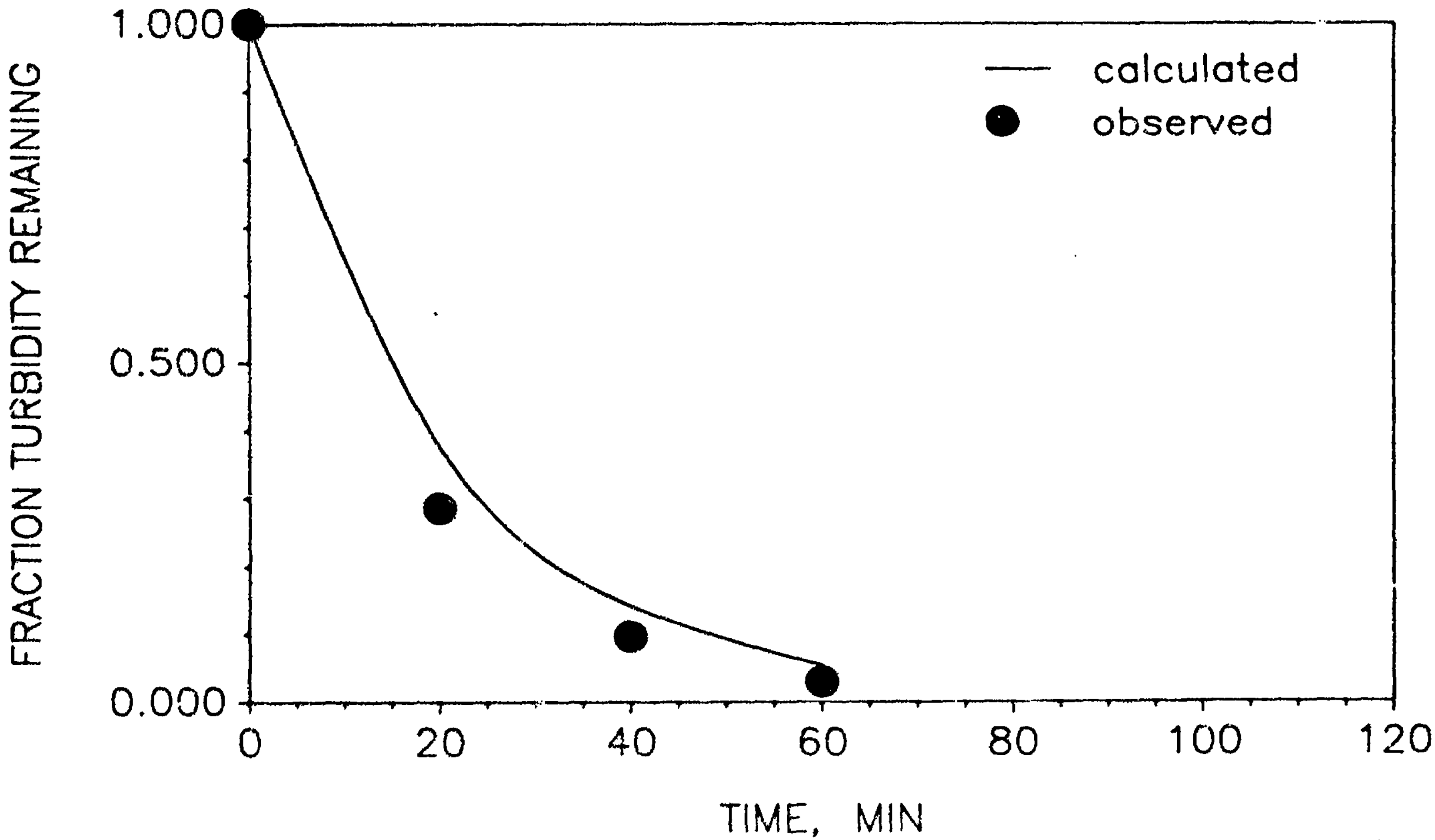

TABLE 4. RUN 4

Time min	Turbidity, feed, NTU	Volume, feed, gal	Temp., feed, °F	Press. psi	Flow, prod. gal/min	Conduct., µmho brine	Conduct., µmho product
0	175	430	80	880	2.95	500[a]	
20	50	430	82	860	3.00		4
40	17	430	85	820	3.00		3
60[b]	9.5	430	88	780	3.00		3
80	5.2	370	90	750	3.00		3
100	2.6	310	93	720	3.00		3
120	1.7	245	97	680	3.00		3
140	0.7	170	100	630	3.00		3.5
160	var[c]	110	104	580	3.00		4.5
170	1.1	75	108	560	3.00	1250	4.5

a. Tap water conductivity was 470 µmho.
b. Product line removed from feed tank at this time.
c. Variable, due to suspended material.

TABLE 5. RECYCLED WATER STANDARDS[a]

Constituent	Maximum acceptable limit
pH	6.5 - 7.5
Turbidity	5 NTU[b]
Hardness	500 mg/L
Free available chlorine[c]	5 mg/L, >20° 10 mg/L, <20°

a. Reference 7.
b. Nephelometric turbidity units.
c. Target residuals with a minimum contact time of 30 min.

Concerning water recovery, overheating of the feed water accompanied concentration greater than 50 percent in USABRDL's studies, but there is no reason at this time to presume that 75 percent recovery as proposed by Lozier and Kuepper[5] cannot be achieved, provided that heat production can be controlled.

TABLE 6. FIELD POTABLE WATER STANDARDS[a]

Constituent	Standard 7 days or less	Standard more than 7 days
PHYSICAL		
Color	-----	50 units
Turbidity	reasonably clear	5 NTU
CHEMICAL		
Arsenic	2.0 mg/L	0.2 mg/L
Chloride	-----	600.0 mg/L
Cyanide	20.0 mg/L	2.0 mg/L
Magnesium	-----	150.0 mg/L
Sulfate		400.0 mg/L
Total dissolved solids		1,500.0 mg/L
pH		5.0-9.0 units
BACTERIOLOGICAL		
Coliform	1.0 per 100 mL	1.0 per 100 mL

a. Reference 7.

CONCLUSIONS AND RECOMMENDATIONS

The RO system tested is capable of generating product water of excellent quality, in terms of TOC, COD, turbidity, and conductivity, from synthetic feed waters containing 17 to 100 mg/L of TOC as soap. Recoveries exceeding 80 percent are achievable. Most of the organic material (soap) is removed by the prefilters rather than the RO module; and it is reasonable to presume that the life of the RO module, i.e., the length of run before fouling, will depend strongly on the frequency of replacement of these filters. Estimation of the mean length of run before RO module fouling and the effect of prefilter replacement thereon await further testing.

Because the life of thin film composite RO modules is shortened at feed water temperatures substantially exceeding 100° F, heat transfer from the high pressure pump to the feed water reservoir is a serious concern. In the case of ROWPU, heat buildup would be a problem because (1) shower wastewater may already be quite warm, (2) there is no provision for heat exchange, and (3) batch operation means that there will be constant heat input to an ever decreasing volume, thereby increasing the temperature even more rapidly. If ROWPU is to be used for shower water recycle in the field, the need for substantial modifications should be anticipated.

Further testing is necessary to establish the mean lifetime of the RO modules and the optimum frequency for changing the prefilters. Research on removal of various organic contaminants from water by RO should continue.[8] If, as seems likely, RO is efficient in exclusion of most organics, it may be possible to omit detailed consideration of health effects related to shower water recycle for this technology.[3]

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GLOSSARY OF TERMS

COD	chemical oxygen demand
gpm	gallons per minute
gph	gallons per hour
NTU	nephelometric turbidity units
psi	pounds per square inch
RO	reverse osmosis
ROWPU	reverse osmosis water purification unit
TDS	total dissolved solids
TFC	thin film composite
TOC	total organic carbon
USABRDL	U.S. Army Biomedical Research and Development Laboratory

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