EVALUATION OF ULTRA-VIOLET RADIATION DISINFECTION ON THE BACTERIAL GROWTH IN THE SWRO PILOT PLANT, AL-JUBAIL[1]

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SUMMARY

The present study summarizes findings of experiment on the evaluation of UV-treatment for bacterial disinfection at SWRO pilot plant at Al-Jubail. Two UV-generation units were installed along the pretreatment line. One before the dual media filter and the second before the micron cartridge filter. The study was carried out at three seawater flow rates: the regular flow operation and two other flow rates below the normal flow. The investigation was carried out at five locations in the plant: raw seawater (RSW), after UV-unit (AUV), after media filter (AMF), after cartridge filter post the second UV-unit (ACF) and brine (BR). The study showed 90-99% reduction in bacterial counts after UV- treatment as compared to raw seawater at the three flow rates suggesting relatively good performance of the first UV-sterilizing unit. However, an increase in bacterial counts were noticed at AMF and ACF. Presumably, the second UV-sterilizing unit has not reduced the bacterial counts in the feed water at this site. Laboratory studies also showed that, incubation of UV-treated samples for 24 h resulted in bacterial recovery and after growth. AMF and ACF also registered reduced TOC, nitrite and phosphate levels in the feed water indicating the presence of a nutrient trap before ACF. A decline in phosphate, nitrite and TOC levels were also found in 24h-incubated samples indicating that bacteria could use nutrients. The study suggests that while UV-treatment considerably reduced bacterial counts in the SWRO plant, stagnant condition of the feed water before CF has presumably led to bacterial recovery and after growth.

Key Words: Ultra-Violet Radiation, Bacterial After growth, Reverse Osmosis, Micronutrients

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1. INTRODUCTION

In the last twenty years the use of UV-radiation technology has been developed and applied on a large scale in treatment of wastewater and drinking water. The germicidal effect of UV-radiation at wavelength ranging from 227 to 329nm was known as early as 1900 [1]. The action spectrum of UV- degermination exhibits a maximum at 270 nm wavelength for most of the microorganisms [2]. It is now well established that killing of cells by UV-radiation is primarily due to deoxyribonucleic acid (DNA) [3]. The UV absorption by DNA is maximal at 260 nm so the UV-radiation at the 260nm is most effective as a lethal agent. Proteins also absorb UV- radiation, but have a peak at 280 nm. The UV-radiation has already been suggested as one of the successful disinfection practices for water treatment [4]. In addition to bacteria, phages, viruses and organic micro pollutants are also killed or degraded by photochemical wet combustion down to and below detection limits of organic carbon [5]. Therefore UV-sterilization has become a practical solution to safe disinfection of drinking water. Also, usage of medium pressure lamps with small reactors has helped to substantially reduce the capital costs of UV-treatment [6].

The seawater reverse osmosis (SWRO) desalination plants face biofouling problems from bacteria originating in feed seawater. The problems are most evident in SWRO plants using surface seawater as feed. Biofouling leads to decreased SWRO membrane performance and thus affects its successful operation. Once bacteria are permitted through the pretreatment system and reach the RO membrane, they divide and colonize the membrane surface building a biofilm and causing membrane fouling.

Most of the disinfection procedures in SWRO plants can be roughly classified into: (1) chemical disinfection by agents like chlorine, chloramine, copper sulfate, chlorine dioxide, hydrogen peroxide and ozone, (2) physical disinfection by agents such as ultraviolet radiation, ultra sound, X-ray and ionizing radiation’s processes. The chemical disinfectants like chlorine and chloramine are widely adopted in pretreatment of SWRO plants. However, control of bacterial growth depends on factors such as disinfectant concentration, its nature and mode of action, density of the organisms and total suspended solid (TSS) content of feed water [4]. These factors make it often extremely difficult to attain absolute disinfection. In addition, chemical disinfectants like chlorine may be hazardous to health directly or through by-products [7]. Chlorine which is the widely used biocide is known to oxidize and degrade the humic substance in seawater, thus resulting in smaller molecules which are assailable organic carbon (AOC) [8]. The AOC in turn become a good nutrient source for bacteria [9] and could result in elevated fast growth of biofilm in the SWRO plants..

On the other hand, UV-treatment offers certain advantages: in a closed system it is safe, it requires only a small space for equipment and it has got immediate germicidal effect [10]. However, incorrect application of UV- radiation in the feed water treatment can be unsuccessful [11] and determining the right dosage for a system is therefore essential. The present study was made to evaluate the UV-radiation disinfection in an SWRO pilot plant at Al-Jubail.

2. EXPERIMENTAL

The study was carried out during June-July, 1996, a period known for its high biological activity of the microorganisms in the seawater [12]. Samples were aseptically collected for bacterial count and after growth studies using standard pour plate method [13] from the following sampling locations: (1) Surface raw seawater (RSW), (2) Seawater After UV-treatment (AUV), (3) After media filter (AMF), (4) After cartridge filter (ACF) following the second UV-treatment, (5) Brine (BR) (Appendix A). Samples were serially diluted and plated using marine agar (Difco 2216). Plates were incubated at 30 ^{0}C for 48-72h [14] and the colony numbers were recorded as colony forming units (CFU). Samples were further incubated at 30 ^{o}C for 24 and 48 hours for determining after growth rates.

In order to monitor the changes in micronutrient concentrations during the UV-treatment process and their possible effects on the bacterial after growth, TOC and micronutrients measurements were carried out. The samples for Total Organic Carbon (TOC) were collected in sterilized glass bottles. TOC was determined by measuring CO_2 released by catalytic combustion of organic carbon using infrared detector. The sample was acidified and total inorganic carbon (TIC) was purged off prior to the analysis. TOC analysis was carried out using a TOC Analyzer-SHIMADZU (Model TOC-500), following the Instruction Manual and USEPA Method [15]. The samples were also collected for analysis of phosphate, nitrite and silicate and analyses were carried out following the methods of Parsons, et al. [16]. Conductivity and pH of the samples were also recorded using a conductivity meter (Yellow Springs Inst. Co.) and a pH meter (Fisher Scientific Co.).

3. RESULTS AND DISCUSSION

The viable bacterial counts observed at different feed flow rates of pretreatment and at different locations of the SWRO pilot plant are given in Table 1. At the three flow rates (2, 4 and 7m^3/h) reduction in bacterial counts was observed at AUV as compared to RSW. While RSW showed 1.21×10^3 CFU/ml, AUV and AMF showed 1.37×10^1 CFU/ml and 76.26×10^1 CFU/ml respectively. The brine (BR) showed an increase in number of bacterial counts as compared to ACF and AMF except on June 2, 1996 when ACF, AMF and BR showed identical growth. At 4m^3/h and 7m^3/h also an increase in bacterial counts was noticed at AMF and ACF. Therefore, the results showed that UV-treatment has drastically reduced the bacterial growth immediately after the first UV-treatment unit but after the media filter and storage tanks the seawater entering the membrane system showed an increase in bacterial counts.

The percentage of reduction in bacterial counts achieved by the UV-treatment is given in Figure 1. The results showed a 90.59 to 99.99% reduction in bacterial growth after UV-treatment as compared to RSW. Out of the sixteen observations fourteen showed reduction above 97%. June 11 and July 2, 1996 showed reduction of 90.59 and 94.21% respectively. However, percentage reduction did not show any relation with flow rates. These results demonstrated that the first UV-unit presently employed in the pilot plant before AMF has substantially inactivated the bacteria in the feed seawater at all the flow rates.

Bacterial after growth at different locations of the SWRO pilot plant after 24 and 48 h incubation time at 30^0C are given in appendix B. AUV was similar to RSW at all the three flow rates tested. AMF, ACF and BR also showed similar bacterial regrowth at the three flow rates suggesting that the bacteria recovered to normal growth after 24 and 48 h, inspite of the UV-treatment. The second UV-sterilization unit appears to have failed to control bacterial growth.

Conductivity values of RSW, AUV and ACF recorded during the study period are given in Table 1. Conductivity values ranged from 59.4-to 60.0 µs/cm at the RSW during the period. A slight elevation (about 1 µs/cm) in conductivity was noticed after 24 h incubation time of samples at 30 ^{0}C. In general, conductivity values were identical at RSW, AUV and ACF. The values of pH ranged from 8.09 to 8.26 at RSW during the period (Table 4). pH values were similar even after 24 h incubation time at 30^{0}C. In general, RSW and AUV showed identical pH but a decrease in pH was found at ACF.

TOC values ranged from 0.90 to 2.60mg/l at RSW during the study period (Table 2). A substantial reduction in TOC values were noticed at RSW, AUV and ACF after incubation of samples for 24h at 30^{0}C. In general, TOC values were less at AUV as compared to RSW except at 7 m^3/h where TOC values were more at the AUV as compared to RSW. At 2 m^3/h a slight increase in TOC was found. However, at 4 m^3/h TOC was slightly less at ACF as compared to AUV and at 7 m^3/h all the three sites showed similar TOC values. In general, TOC values declined after UV- treatment and after 24 h incubation time at 30^{0}C.

Phosphate concentration at RSW ranged from 0.55 to 1.22 µg as PO_4 -P/l during the study period (Table 3). Phosphate values declined at 2 and 4 m^3/h when incubated for 24h at 30^{0}C. However, at 7 m^3/h the values remained the same even after 24h incubation at 30^{0}C. In general phosphate levels were identical at RSW, AUV and ACF. Silicate levels ranged from 3.84 to 18.42 µg SiO_2 - Si/l. There was no considerable change in silicate concentration even after 24h incubation at 30^{0}C. At 2 and 4 m^3/h RSW and AUV showed identical silicate levels but slightly high values were found at ACF. At 7 m^3/h a reduction in silicate values were found at AUV and ACF as compared to RSW. Nitrite levels were relatively low and a reduction in nitrite levels were found after 24 h incubation time at 30^{0}C. Elevated nitrite levels were found at AUV. The results showed that phosphate and nitrite levels are reduced after 24 h incubation time and silicate levels were almost identical before and after the incubation.

The germicidal effect of UV-radiation is dependent on several factors such as total dissolved solids (TDS), total suspended particles (TSS), conductivity, total organic carbon (TOC), total hardness, sensitivity and type of microorganisms [4]. The present study showed that UV-treatment has resulted in a drastic reduction in bacterial counts at the R&D SWRO pilot plant. The number of the viable bacteria count at a flow rate of 2 m^3/h (residence time 22) showed a percentage reduction of 98.87 after the UV-treatment. Other flow rates; 4 and 7m^3/h (11 and 6 sec residence time, respectively) had achieved 97.24 and 98.88 percentage of reduction respectively. In total, the UV-radiation treatment employed in the pilot plant before MF achieved a high percentage kill of bacteria at the three flow rates.

However, AMF, ACF and Brine samples showed an increase in bacterial counts suggesting that the second UV-sterilization unit is not successful in controlling bacterial growth. The results showed that the source for increase in bacterial counts at the AMF and ACF appears to be due to recovery of bacteria after first UV- treatment. ACF and brine samples showed similar bacterial counts. Gaudy and Gaudy [4] reported that UV light less effects on spore-forming and slowly-growing cells than vegetative and rapidly growing cells. Johnson et al. [17] have reported that there is increasing evidence that bacterial photo reactivation (recovery after exposure to light) may be significant concern in UV-disinfection of secondary effluent which is commonly discharged into open receiving systems in the United States. Harris et al., [18] also reported that sunlight penetrating the effluent receiving water might reactivate a significant fraction of the UV-inactivated bacteria. Photo reactivation often repair much of the damage to the DNA. Evidence of photo reactivation after UV treatment has been reported for fecal streptococci and coliforms [19] The after growth studies carried out in the present study also showed that 24h incubation time of UV-treated samples at 30^0C has resulted in normal bacterial counts (of untreated seawater). All samples had similar growth after 24h in spite of the UV-treatment. Therefore, it is reasonable to assume that in the SWRO plant, bacteria after the UV- treatment have received ample time to recover prior to the cartridge filter (CF). It is also possible that 1-2% live bacteria, which tolerate UV-treatment, could multiply in the storage tanks under favorable conditions such as availability of nutrients. The present study on the 24 h incubation time of bacteria has shown that bacteria use phosphate and nitrite and this has resulted in the depletion of these nutrients. While phosphate concentrations were unaffected by the UV-treatment, an increase in nitrite levels after UV-treatment was noticed. However, at ACF the levels of phosphate and nitrite declined suggesting a nutrient trap prior to ACF. Presumably due to consumption by bacteria in the storage tanks where the UV-treated feed water is stored. Nitrite is one source of nitrogen to organisms and only organisms possessing necessary enzymes can utilize nitrite as a source of cellular nitrogen [4]. Fenchel and Harrison [20] also showed that after inoculation of bacteria, the concentration of phosphate in the water rapidly decreased and the decrease was related to phosphorus consumption. It was also noticed that if the water was enriched with inorganic nitrogen source, bacterial growth was more rapid. In natural systems, the phosphate is released from bacteria when grazed by ciliates [21]. However, at $7m^3/h$ AUV and ACF had identical phosphate levels. Therefore at $7m^3/h$, increased flow appears to mask the difference between AUV and ACF. The laboratory results also suggested that nutrient consumption takes place during bacterial growth and support the hypothesis that the observed nutrient consumption prior to ACF is due to bacteria. This showed that determination of micronutrients could be helpful to draw conclusions about the bacterial after growth dynamics.

TOC values also showed a slight reduction after UV-treatment except at $7m^3/h$. However, a substantial reduction in TOC was found at ACF except at $2m^3/h$. Active bacteria exude dissolved organic matter in connection with the decomposition of organic material [22]. In static systems, the process consists of hydrolysis of particulate carbon using extra cellular enzymes and later the bacteria assimilate the dissolved organic substrates. The TOC value therefore depends on concentration of substrate and rate of bacterial metabolism including assimilation [23]. Substrates at low concentrations were utilized more efficiently in the presence of inert particles such as sand but not in the absence of substrate or when it is present in high concentrations [24]. Apparently the reduction observed at AUV in the present study is due to physical and chemical change caused by UV-radiation as UV-treatment can result in decarboxylation of compounds including humic acids [25]. However, further decline in TOC at the ACF appears to be due to consumption by bacteria. Absence of such TOC consumption at 2-m^3/h-flow rate (not operational flow) remains unclear at this point. Results of the laboratory study also showed reduction in TOC levels associated with bacterial after growth. More than 50% reduction in TOC was evident after 24 h incubation time.

The results of the present study showed that the significant increase in bacterial count at ACF is presumably due to bacterial aftergrowth. This data are comparable to the result from Al-Birk SWRO plant; where the bacterial aftergrowth rates increased after chlorinating point and the aftergrowth rate was substantially high. It is mentioned that chlorine degrades humic acids into small molecules which can be assimilated by bacteria. This seems also true for UV radiation and could result in bacterial aftergrowth. Li, et al., [24] found that there is a slight decay of humic acids after UV-treatment presumably due to decarboxylation. While details of chemical changes under UV-treatment is not clear at this point, it appears that the UV-treatment also result in bacterial after growth and therefore the net result of bactericidal action may resemble chlorine disinfection. It has been observed that even at the same flow rate the percentage kill by the UV-radiation was subject to fluctuations at different sampling dates. This is to be expected because it is known that the suspended matter in water column affects the efficacy of UV-radiation. A turbidity increase could cause decline in the percentage of kill.

4. COST ANALYSIS

Cost analysis of UV-radiation was calculated to be approximately 0.73 SR per cubic meter of water (Table 5). UV lamps require replacement after each 8000 hours and this appears to be the only maintenance cost for the UV-unit. Chlorination would cost about 0.75 SR per cubic meter of water with relatively high operation and maintenance cost to achieve similar disinfection efficiency The after growth rates of both technologies are comparable.

5. CONCLUSIONS

The following conclusions were drawn from the present study.

1. The study showed a reduction (about 90-99.9%) in bacterial counts after the UV-treatment suggesting the excellent performance of the first UV-treatment unit in pretreatment section of the SWRO pilot plant.
2. At all the flow rates, the bacterial counts increased through the pretreatment stage specially at the AMF and ACF suggesting that the second UV-sterilization unit has failed to control bacterial growth. This also indicates bacterial recovery and after growth from UV-treatment.
3. The laboratory studies have shown that bacteria recovers from the UV- treatment within 24 h and after growth were similar to untreated samples.

4. The results of laboratory analysis of TOC and micronutrients suggest that the bacterial after growth following UV-treatment resembles chlorination disinfection.
5. The following are the advantages of the UV-radiation for disinfection: 1. Showed 90-99.9% reduction of bacteria., 2. Relatively less maintenance cost, 3. Require less space for equipment, 4. Minimal supervision., 5. Unlike chlorination, UV-radiation does not facilitate corrosion. UV-radiation did not cause any phase change in water and therefore does not lead to any large-scale accumulation of toxic by-products.

In summary, UV-radiation appears to be a potential alternative to chlorination, if it is employed in plant with continuous flow of water. This would considerably minimize the operation and maintenance cost and avoid other plant problems allied with the chlorination, particularly discharge of toxic chlorine by-products such as trihalomethanes into the receiving water. However, the storage of UV-treated water in tanks during its passage through different stages of the plant could permit bacterial reactivation and recovery as evident in the present study. This could eventually affect the plant performance.

6. RECOMMENDATIONS

1. Since suspended particles could affect the efficiency of UV-radiation treatment, the UV-unit may be installed after the dual media and cartridge filters and right before the SWRO membrane to improve the plant performance.
2. When cost of the UV-radiation disinfection was compared to chlorination, it appears to be an alternative to chlorine disinfection in plants where there is facility for continuous flow of water without stagnation.
3. To increase the performance of UV-radiation disinfection process in the SWRO pilot plant, stagnant conditions of water flow such as storage of water in the tanks may be avoided.

Table 1. Viable bacterial counts (CFU/ml) seawater at different flow rates and at different stages of the SWRO pilot plant

Sampling date	Sampling Location*				
	RSW	**AUV**	**AMF**	**ACF**	**BR**
(2m^{3}/h Flow rate)					
June 2, 1996	$1.47x10^{3}$	$1.53x10^{1}$	$1.84x10^{3}$	$4.60x10^{3}$	$1.26x10^{3}$
June 4, 1996	$1.00x10^{3}$	$0.80x10^{1}$	$1.63x10^{2}$	$5.12x10^{2}$	$7.76x10^{3}$
June 4, 1996	$1.17x10^{3}$	$1.80x10^{1}$	$2.85x10^{2}$	$5.46x10^{2}$	$1.35x10^{3}$
(4 m^{3}/h Flow rate)					
June 8, 1996	$1.15x10^{4}$	$2.51x10^{1}$	$1.609x10^{2}$	$1.62x10^{3}$	$1.39x10^{4}$
June 9, 1996	$1.36x10^{3}$	$3.08x10^{2}$	$3.98x10^{2}$	$5.10x10^{1}$	$8.06x10^{3}$
June 10, 1996	$3.34x10^{3}$	$8.94x10^{1}$	$2.01x10^{2}$	$3.78x10^{1}$	$6.77x10^{3}$
June 11, 1996	$3.32x10^{3}$	$3.12x10^{2}$	$5.47x10^{2}$	$1.03x10^{2}$	$3.15x10^{3}$
June 16, 1996	$1.33x10^{4}$	$0.40x10^{1}$	$5.33x10^{3}$	$2.03x10^{2}$	$6.77x10^{3}$
June 17, 1996	$2.10x10^{3}$	$0.60x10^{1}$	$5.20x10^{2}$	$2.05x10^{2}$	$5.95x10^{3}$
(7 m^{3}/h Flow rate)					
June 30, 1996	$1.46x10^{4}$	2.50x101	$2.18x10^{4}$	$1.43x10^{4}$	$9.05x10^{3}$
July 2, 1996	$3.87x10^{3}$	2.24x102	$1.35x10^{4}$	$3.32x10^{2}$	$1.16x10^{4}$
July 6, 1996	$4.25x10^{3}$	1.27x102	$2.57x10^{3}$	$6.68x10^{3}$	$8.94x10^{3}$
July 7, 1996	$5.22x10^{3}$	8.88x102	$3.28x10^{3}$	$1.03x10^{3}$	$1.02x10^{4}$
July 8, 1996	$5.72x10^{3}$	3.88x102	$2.70x10^{3}$	$2.18x10^{3}$	$1.91x10^{4}$
July 9, 1996	$1.99x10^{4}$	1.18x102	$4.76x10^{2}$	$3.82x10^{3}$	$7.28x10^{3}$
July 10, 1996	$1.43x10^{4}$	4.51x101	$2.99x10^{2}$	$2.49x10^{5}$	$1.38x10^{4}$

*RWS = Raw seawater
AUV = After ultra-violet radiation treatment
AMF = After dual media filter
ACF = After micron cartridge filter
BR = Brine reject

Table 2. Conductivity and pH of seawater at different flow rates and pretreatment stages of the SWRO pilot plant (24 h after growth values are given in parenthesis)

Sample source	Conductivity (μs/cm)			pH		
	2 m^3/h	4 m^3/h	7 m^3/h	2 m^3/h	4 m^3/h	7 m^3/h
RSW	59.40	59.50	60.00	8.26	8.10	8.9
	(60.40)	(59.40)	(60.00)	(8.15)	(8.17)	(8.13)
AUV	59.40	60.00	60.70	8.16	8.14	8.1
	(61.00)	(60.00)	(60.60)	(8.15)	(8.17)	(8.07)
ACF	ND	59.60	60.20	ND	7.82	8.01
	(59.80)	(59.50)	(60.30)	(7.72)	(7.62)	(7.80)

ND- No Data

Table 3. Total Organic Carbon (TOC) in seawater at different flow rates and pretreatment stages of the SWRO pilot plant (24 h after growth values are given in parenthesis)

Sample source	TOC (mg/l) 2 m^3/h	TOC (mg/l) 4 m^3/h	TOC (mg/l) 7 m^3/h
RSW	2.60	1.82	0.90
	(1.13)	(0.81)	(0.95)
AUV	1.46	1.59	1.23
	(0.48)	(0.76)	(0.76)
ACF	2.03	0.71	0.80
	(0.33)	(0.53)	(0.72)

Table 4. Micronutrients in seawater at different flow rates and at different locations of the SWRO pilot plant (24 h after growth values are given in parenthesis)

Sample source	Phosphate (ug /l Po_4-P) 2 m^3/h	4 m^3/h	7 m^3/h	Silicate (ug/l Sio_3-Si) 2 m^3/h	4 m^3/h	7 m^3/h	Nitrite (ug/l No_2-N) 2 m^3/h	4 m^3/h	7 m^3/h
RSW	1.22	1.29	0.55	3.84	4.02	18.42	BDL	BDL	BDL
	(0.14)	(0.33)	(0.50)	(4.50)	(3.94)	(15.08)	(BDL)	(BDL)	(BDL)
AUV	1.22	0.64	0.55	3.84	4.69	10.52	3.03	6.06	BDL
	(0.68)	(0.11)	(0.75)	(4.75)	(4.65)	(8.77)	(2.42)	(BDL)	(BDL)
ACF	ND	0.64	0.55	ND	6.54	11.84	ND	BDL	BDL
	(0.41)	(0.22)	(0.50)	(7.0)	(6.08)	(6.66)	(1.52)	(BDL)	(BDL)

BDL- Below Detection Limit ND- No Data

Table 5. Cost analyses of UV-radiation vs. Chlorination

Description	UV-radiation	Chlorine (approx)
Unit Cost	4348.00	2000.00
Operation Cost	Nil	4000.00
Maintenance Cost	3827.00 / Lamp	2000.00
Chemical Cost	Nil	448.00
Total	8175.00	8448.00
Cost / m^3	0.73	0.75
*Bacterial disinfection Efficiency (%)	90 – 99.9	**98.0
**Aftergrowth (k/h)	0.19	0.16

*Chlorine cost calculated at 2ppm dosing (hypo chlorite 4.00 SR/m^3)

**(Munshi et al.[12].

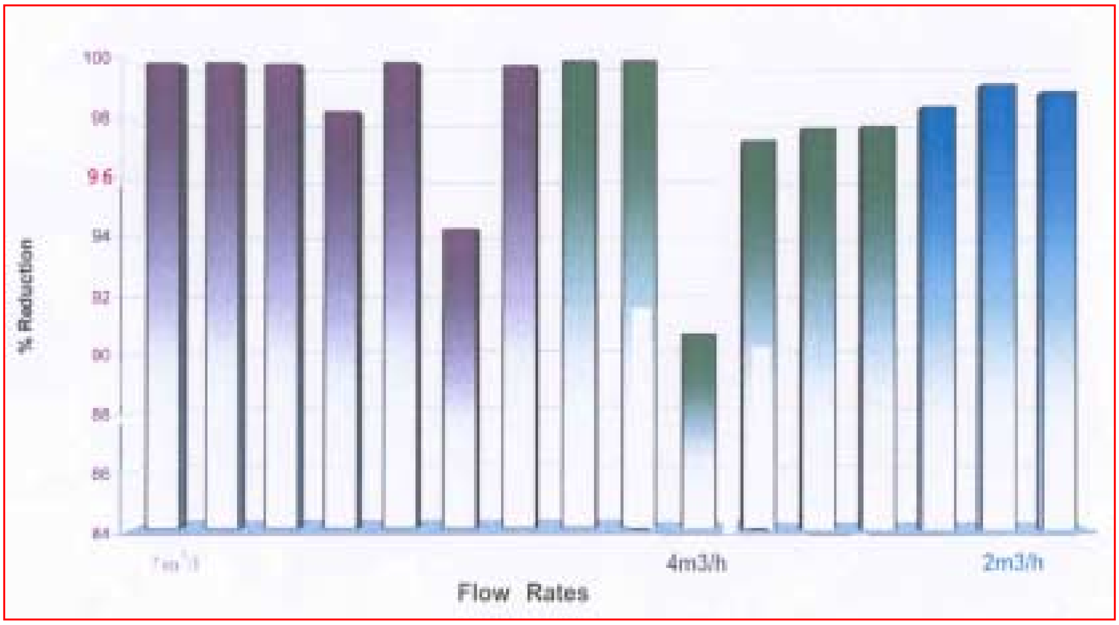

Figure 1. Percentage Reduction in Bacterial Count After Exposure to UV-Radiation

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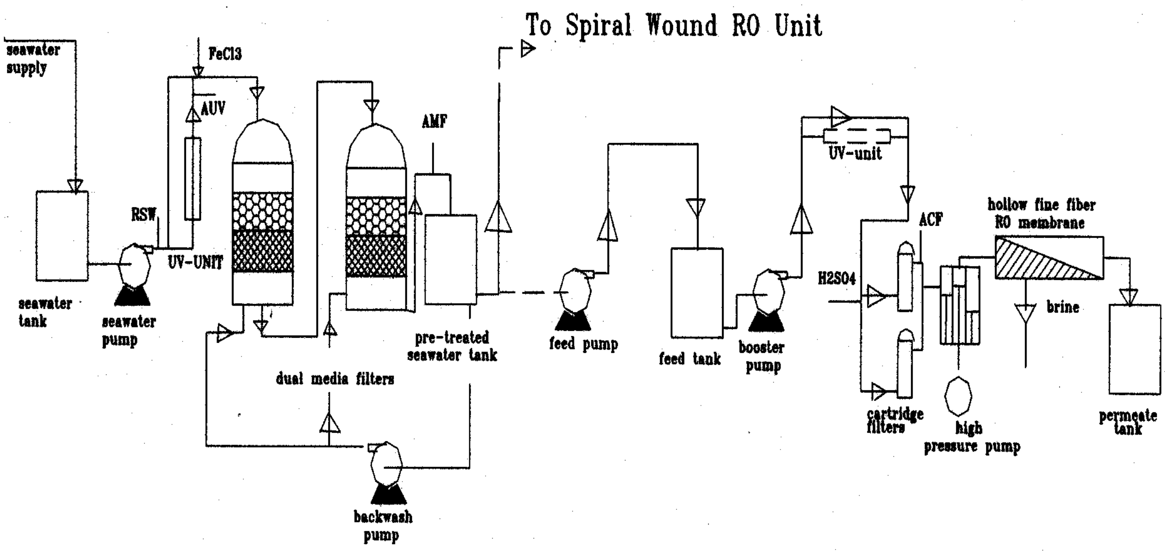
Appendix A



A schematic flow diagram of the SWRO pilot plant consisting of a common pretreatment and UV-sterilization unit

Sampling points : RSW = raw seawater, AUV = after UV-unit, AMF = after media filter, ACF= after cartridge filter and brine

Appendix B

24 and 48h bacterial after growth counts (CFU/ml) in seawater at different flow rates and locations of the SWRO pilot plant (48h after growth values are given in parenthesis)

Sampling date	Sampling stage				
	RSW	AUV	AMF	ACF	BR
(2 m3/h Flow rate)					
June 03, 1996	$1.88x10^5$	$2.13x10^4$	$6.53x10^4$	$3.36x10^5$	$6.51x10^4$
[June 04, 1999]	[NA]	[NA]	[NA]	[NA]	[NA]
June 05, 1996	$9.66x10^4$	TNTC	$9.26x10^4$	TNTC	TNTC
[June 06, 1996]	[$1.46x10^5$]	[$4.03x10^5$]	[$1.41x10^5$]	[$1.3x10^5$]	[$4.06x10^5$]
June 04, 1996	$2.63x10^4$	$4.10x10^3$	$7.03x10^5$	$1.50x10^5$	$1.20x10^5$
[June 05, 1999]	[NA]	[NA]	[NA]	[NA]	[NA]
Mean	$1.04x10^5$	$1.27x10^4$	$2.86x10^5$	$2.43x10^5$	$9.25x10^4$
[Mean]	[$1.04x10^5$]	[$4.03x10^5$]	[$1.41x10^5$]	[$1.3x10^5$]	[$4.06x10^5$]
(4 m3/h Flow rate)					
June 09, 1996	$1.24x10^4$	$8.53x10^3$	$1.23x10^4$	$6.68x10^5$	$2.66x10^5$
[June 10, 1996]	[$3.00x10^6$]	[$1.41x10^5$]	[$1.26x10^5$]	[$8.3x10^5$]	[$1.31x10^5$]
June 10, 1996	$3.65x10^4$	$9.80x10^4$	$4.70x10^4$	$3.20x10^5$	9.96x10
[June 11, 1996]	[$1.41x10^5$]	[$2.75x10^5$]	[$1.88x10^5$]	[$3.5x10^4$]	[$9.73x10^5$]
June 11, 1996	$3.07x10^5$	$3.25x10^5$	$5.93x10^4$	$8.70x10^4$	$1.41x10^5$
[June 12, 1996]	[$2.44x10^5$]	[$1.71x10^6$]	[$9.56x10^4$]	[$3.9x10^5$]	[$3.25x10^5$]
June 12, 1996	$5.40x10^4$	$1.31x10^5$	$3.23x10^4$	$3.05x10^4$	$5.65x10^4$
[June 13, 1996]	[NA]	[NA]	[NA]	[NA]	[NA]
June 17, 1996	$7.80x10^4$	$2.43x10^4$	$2.00x10^5$	$3.30x10^5$	$1.42x10^5$
[June 18, 1996]	[$1.57x10^4$]	[$4.70x10^5$]	[$1.26x10^5$]	[$1.7x10^5$]	[$5.20x10^5$]
June 18, 1996	$8.05x10^4$	$4.40x10^4$	$7.10x10^4$	$1.56x10^5$	$1.32x10^5$
[June 19, 1996]	[$7.20x10^4$]	[$4.15x10^5$]	[$1.25x10^4$]	[$1.5x10^4$]	[$3.50x10^6$]
Mean	$1.12x10^5$	$1.26x10^5$	$8.44x10^4$	$3.18x10^5$	$1.67x10^5$
[Mean]	[$6.94x10^5$]	[$6.02x10^5$]	[$1.09x10^5$]	[$2.9x10^5$]	[$1.09x10^6$]
(7 m3/h Flow rate)					
July 01, 1996	$3.04x10^5$	$1.40x10^6$	$4.60x10^6$	$1.32x10^4$	$1.27x10^5$
[July 01, 1996]	[TNTC]	[$5.53x10^5$]	[$5.11x10^5$]	[TNTC]	[$5.33x10^5$]
July 03, 1996	$1.40x10^5$	$6.07x10^5$	$3.96x10^4$	$2.44x10^5$	$8.63x10^4$
[July 03, 1996]	[NA]	[NA]	[NA]	[NA]	[NA]
July 07, 1996	$5.70x10^3$	$1.31x10^5$	$7.55x10^4$	$3.10x10^5$	$2.89x10^5$
[July 08, 1996]	[$1.30x10^5$]	[$1.45x10^5$]	[$2.40x10^4$]	[$4.8x10^5$]	[$5.36x10^5$]
July 08, 1996	$3.00x10^4$	$3.52x10^5$	$3.29x10^6$	$8.00x10^5$	$2.02x10^5$
[July 09, 1996]	[$4.00x10^5$]	[$1.48x10^5$]	[$4.45x10^5$]	[$6.2x10^4$]	[$3.40x10^5$]
July 09, 1996	$1.95x10^4$	$1.66x10^5$	$1.78x10^4$	$1.77x10^5$	$2.10x10^5$
[July 10, 1996]	[$1.05x10^5$]	[$2.05x10^5$]	[$2.00x10^4$]	[$1.3x10^5$]	[$1.35x10^5$]
July 10, 1996	$1.76x10^5$	$2.65x10^5$	$1.07x10^4$	$2.07x10^5$	$1.03x10^5$
[July 11, 1996]	[NA]	[NA]	[NA]	[NA]	[NA]
Mean	$1.12x10^5$	$4.87x10^5$	$1.34x10^6$	$2.92x10^5$	$1.69x10^5$
[Mean]	[$9.16x10^5$]	[$2.62x10^5$]	[$2.04x10^5$]	[$2.2x10^5$]	[$3.86x10^5$]