PILOT SCALE DESALINATION OF SEA-WATER BY REVERSE OSMOSIS

by

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ABSTRACT

The desalination of sea-water by reverse osmosis for the production of potable water was investigated by pilot study.

Emphasis was placed on the selection of an efficient pretreatment regime. The use of a low-cost tubular ultrafiltration system in combination with dual media and cartridge filtration produced RO feedwater of excellent quality, irrespective of the raw sea-water quality. Although fouling of the UF membranes was experienced, flux restoration could be effected with the aid of sponge balls.

With the addition of scale inhibitor RO recoveries in excess of 40% could be obtained without detrimental effect to the membranes. The quality of the product water from the single stage RO unit was well within the recommended SABS limits for domestic supplies. No RO membrane fouling was noticed.

ACKNOWLEDGEMENTS

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Pilot scale desalination of sea-water by reverse osmosis

would not have been possible.

The author would like to express his sincere thanks to the staff of DRL and Membratek for their support.

Gratitude is extended to DRL for assistance and co-operation in the execution of this project.

LIST OF ABBREVIATIONS

CSIR	Council for Scientific and Industrial Research
DMF	Dual media filter
DRL	Diamond Research Laboratory (DeBeers)
DWA	Department of Water Affairs
EDAX	Energy Dispersive Analysis by X-rays
EDTA	Ethylene diamine tetra-acetic acid
HFF	Hollow fine fibre
LMH	Membrane productivity - volume rate of permeate flow expressed as litres per square metre area per hour
MEMTUF	Membratek's low-cost unsupported tubular ultrafiltration system
MMCO	Molecular mass cut-off
MSF	Multi-stage flash
NIWR	National Institute for Water Research
NTU	Nephelometric turbidity unit
PVP	Poly(vinyl pyrrolidone)
RO	Reverse osmosis
SDI	Silt density index
SEM	Scanning electron microscope
SS	Stainless steel
SWUF	Sea-water ultrafiltration
TUF	Tubular ultrafiltration
UF	Ultrafiltration
uPVC	unplasticised polyvinylchloride
WRC	Water Research Commission

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SECTION ONE : INTRODUCTION

1.1 BACKGROUND TO RO AND SEA-WATER DESALINATION

Reverse osmosis membranes have been used commercially for the desalination of saline, aqueous solutions since the development of asymmetric cellulose acetate membranes by Loeb and Sourirajan *(1962)* in the early 1960's. Today most major membrane manufacturers, e.g. DuPont (USA), Toyobo (Japan) and Filmtec (USA) produce membranes from synthetic polymers which are specifically tailored for the desalination of sea-water.

The production of potable water from sea-water by reverse osmosis gained considerable ground during the mid-seventies with major installations being erected in the Middle East. The operating cost of desalination by RO is lower when compared to distillation or MSF evaporation since no phase change is involved. Economics, high energy consumption and advances in the development of RO technology are given as the main causes for the decline in market share of MSF evaporation from 67% in the early 1980's to 3% in 1989, whereas RO showed a corresponding increase from 23% to 85% during this period *(Ahmed, 1991)*. The current installed world-wide RO capacity is estimated at 13 297 000 m^3/day *(Wangnick, 1991)*. This figure includes both brackish and sea-water applications.

Due to the modular design of membrane systems, their capacity can be varied relatively easily, with future expansion being facilitated by the installation of additional modular units, rather than complicated plant extensions. Typical examples of successful large RO installations for the production of potable water from sea-water are the 20 000 m^3/day plant at Ghar Lapsi, Malta *(DuPont, 1986a)* and the 46 000 m^3/day plant at Ras Abu Jarjur, Bahrain *(DuPont, 1986b)*.

To date a variety of RO plants, with capacities ranging from 100 to 9 000 m^3/day, have been installed in the RSA for the desalination of brackish waters and the treatment of industrial effluents. Unfortunately RO has not yet been applied for the desalination of sea-water for potable purposes, on a commercial scale, by land-based installations. The potential of RO to desalinate sea-water is nevertheless realised in the fishing industry and the SA Navy where a number of vessels are equipped with small units, so-called *watermakers*. The design and construction of these units, from an engineering point of view, is often poor with ineffective pre-treatment, if any. In a recent investigation with regard to the use of RO in the desalination of sea-water for the production of potable water in naval applications the following system design and operational problems were identified:

a) *HIGH PRESSURE PUMPS.* Poor selection for the particular duty and operation at high revolutions of the plunger pumps resulted in excessive vibration and breakdown. Difficulties in obtaining spares for the imported pumps were experienced due to lack of representation by local agents.

b) *PULSATION AND NOISE BY PUMPS.* Incorrect sizing and routing of inlet plumbing caused high mechanical noise and cavitation. The fitting of suitable pulsation dampeners could have reduced the pressure pulsations, which are associated with reciprocal, positive displacement pumps, considerably. Similar problems were experienced by Membratek with a large industrial RO plant, but could be overcome by the installation of pulsation dampeners *(Enever, 1984).*

c) *PRE-TREATMENT.* Inadequate and inappropriate pretreatment equipment led to premature RO membrane fouling with resultant decline in capacity and product quality.

These problems have led to the perception by the market that RO is unreliable and expensive, although its ability to produce potable water from sea-water is accepted.

This misconception can only be corrected by demonstrating the capabilities of properly engineered plants to the market. Initially this has to be done on a pilot plant level in co-operation with parties and commercial companies who show an interest in the process and who are willing to invest in its local development.

1.2 SWAKOPMUND SEA-WATER DESALINATION TRIALS

Unfortunately, the track record of local pilot-scale trials, concerning the desalination of sea-water by reverse osmosis, is not inspiring.

A three year pilot study to investigate the desalination of sea-water was conducted from August 1978 to September 1980 at Mile 4 near Swakopmund in South West Africa/Namibia *(DWA-SWA and CSIR, 1981).* The project was a joint venture by the Water Research Commission (WRC), the Department of Water Affairs (DWA) and the Council for Scientific and Industrial Research (CSIR) through the National Institute for Water Research (NIWR).

The Swakopmund site was chosen for pilot studies based on projections of water supply and demand for the Central Namib Water Scheme which were undertaken in 1976. These indicated that all fresh water sources might be exploited to their limit by the late 1980's. The desalination of sea-water appeared to be the most viable option to supplement water supplies. The decision was made to investigate the feasibility of using reverse osmosis for this purpose on a pilot scale.

1.2.1 STUDY OBJECTIVES

The major objectives of the study, as set out in the final project report, were as follows:

a) To produce 200 to 300 m^3/day of potable water from sea-water for supply purposes;
b) to study the technology available at the time in order to establish design criteria for large scale sea-water RO plants;
c) to permit the evaluation of selected commercial RO systems;
d) to acquire expertise and experience in the design, construction and operation of a RO plant for the desalination of sea-water.

1.2.2 RESEARCH INVESTIGATIONS

The research that was conducted, covered a variety of aspects besides the actual operation of the RO systems. These included collection of data on weather conditions, a literature study into the constituents of sea-water, an investigation into the quality of sea-water at the pilot study site and other research aspects e.g. instrumentation, automatic plugging meter.

The more important aspects of the study consisted of the different pretreatment methods and RO systems which were evaluated, *viz.*

CONVENTIONAL PRETREATMENT. This comprised clarification, sedimentation and filtration;

UVOX PRETREATMENT. Chlorination of raw sea-water followed by ageing in ponds with ultra-violet irradiation from the sun;

ENVIROGENICS RO UNIT. Two stage unit using cellulose acetate spiral-wound elements;

DuPONT RO UNIT. Single stage unit with hollow fine-fibre polyamide membranes in the form of B-10 permeators;

UOP/ROGA RO UNIT. Tested as a single stage unit with PA-300 type composite spiral-wound membranes.

It was demonstrated that the RO units were capable of producing water of potable quality initially, but that a premature decline in capacity and salt rejection performance occurred. This was attributed to operational problems with pretreatment and maintenance, which at times resulted in the membranes being subjected to the following:

a) contamination by grease from pumps;
b) chlorine break-through from the pretreatment section;
c) unknown membrane foulants which were not removed by pretreatment and could not be detected by the plugging index determination;
d) bacterial contamination.

1.2.3 PILOT STUDY FINDINGS AND CONCLUSIONS

Each of the abovementioned factors, but especially a combination of them, is detrimental to the performance of the RO membranes. As such the results that were obtained proved to be inconclusive.

It was therefore not possible to make a firm recommendation for the selection of any particular membrane system for a full-scale plant or to estimate membrane lifetime and cost.

On the positive side the project demonstrated the need for proper engineering, effective pretreatment and plant control. The following aspects, in particular, were highlighted:

a) *PRETREATMENT.* Conventional pretreatment was often incapable of delivering RO feedwater within the specified plugging index. UVOX could provide RO feedwater of acceptable quality consistently, but the economics were doubtful due to the high levels of chlorine required and the fact that sea-water RO systems are only capable of 30-35% recovery rates. In other words 65-70% of the pretreated sea-water is wasted as brine.

b) *RO SYSTEM.* The DuPont B-10 permeators were found to be mechanically reliable and the construction without brine seals (unlike the case in spiral-wound units) was considered to be an advantage. The efficiency of the tannic acid treatment,for *insitu* restoration of salt rejection ability, was successfully demonstrated.

c) *HIGH PRESSURE PUMPS.* Numerous problems were experienced with the high pressure plunger pumps, ranging from seized bearings, pitting of valves and cracked plungers to water leaks past the plunger packings. It was also thought that vibration from the high pressure pumps may have caused damage to some of the DuPont permeators. The problems experienced during the study emphasize the need for selection of high pressure pumps which are specifically designed and engineered for RO applications, especially with regard to construction and material selection. The correct sizing of suction and discharge piping as well as the optimum positioning of pulsation dampeners has to be considered during the design plant stage.

d) *BACTERIAL CONTROL.* When using chlorine as a bactericide, extreme precautions must be taken to prevent chlorine breakthrough from the pretreatment section. Although chlorine is very effective in combating bacterial growth, most RO membranes are very sensitive to chlorine. Chlorine breakthrough is fatal to the performance of the RO membranes, as was demonstrated in the Swakopmund study.

1.3 BACKGROUND TO PRESENT RO DESALINATION TRIALS

It follows that the operational problems which were experienced during the Swakopmund pilot study (refer section 1.2.3) are similar to those still experienced on small RO units which are presently used in naval and fishing applications (section 1.1). It is surprising that these problems have persisted for the past decade, in spite of the fact that the ability of RO in the desalination of sea-water has been successfully demonstrated with large plants worldwide.

This situation can only be explained in terms of lack of knowledge to apply known engineering principles in this field.

As a result the local market's perception of RO technology is poor and misconceived as to the reliability and cost associated with the process. As mentioned earlier, this perception can only be changed through demonstration of the capability of the process in pilot studies, preferably to an end-user. This requires the co-operation of industry and commercial companies who are willing to invest time and money in preliminary work, since it is largely a task of education and convincing them of the potential benefits of RO.

A fortunate opportunity presented itself when the Diamond Research Laboratory (DRL) of DeBeers expressed their belief that the advances which had been made in membrane systems during the past decade, now allowed the desalination of sea-water by RO as a viable proposition, provided a correctly engineered plant was constructed. Membratek, on the other hand, had gained considerable experience with regard to the design, construction and operation of RO systems during the past twelve years. These factors, combined with being the DuPont licensee, which provided access to Permasep products e.g. B-10 sea-water permeators and engineering know-how of the parent company, provided the vital ingredients for successful desalination trials.

1.4 ELIZABETH BAY SEA-WATER DESALINATION TRIALS

The need to supply relatively small quantities of potable water to mining operations at remote locations along the West Coast had been realised by DeBeers Consolidated Mines for some time. The use of RO for the desalination of sea-water was proposed by DRL, the research organisation of DeBeers.

In order to establish the technical feasibility and costs of the process, a sophisticated pilot plant was constructed by DRL in conjunction with Membratek. Details of the pilot plant are presented in Section 2: Experimental Equipment and Site.

A suitable test site had to be selected at one of the mines for conducting the proposed pilot study. Several sites in Namaqualand and Namibia were considered. The final selection was made according to the following criteria:

a) *SEA-WATER.* Untreated, raw sea-water had to be available at a rate of 45 m^3/day, drawn preferably from an existing sea-water intake;
b) *POTABLE WATER.* Small quantities of potable water were required for cleaning purposes and make-up of chemicals. This could also be supplied by the RO plant, once operational;
c) *ELECTRICAL SUPPLY.* The pilot plant requirements were 20A (220V AC) for single phase and 10kW (380V AC) for three phase;

d) *WASTE DISPOSAL.* UF retentate and RO brine had to be disposed of at a rate of 30 m^3/day;

e) *FLAT AREA.* A suitable level area approximately 8x4 metres on which the pilot plant container could be placed, had to be available.

f) *ACCESS.* Since most of the possible sites were classified as restricted areas due to diamond mining operations, ease of access by personnel and subsequent removal of equipment were desired.

Although remote and not easily accessible, Elizabeth Bay was selected as the most suitable site which could satisfy all the abovementioned requirements. Since actual mining operations had not yet started (ore sampling was in progress) the removal of the pilot plant after the completion of the study was possible. Normally once equipment enters a diamond restricted area it is not allowed to leave that area again.

Elizabeth Bay is situated approximately 35 km south of Lüderitz on the Namibian coast. The surrounding desert area is rich in diamond deposits and has been mined by the Germans in the then Deutsch-Südwest Afrika since the turn of the century. The nearby ghost town of Kolmanskop is a well-known tourist attraction. The mining rights to the area have since been obtained by DeBeers who subsequently closed down these mines. With the recent upswing in the diamond price, the decision was made by DeBeers to exploit these old diamond areas again. This has resulted in the construction of a diamond processing plant at Elizabeth Bay. Although the personnel will not reside at mine, about 15 m^3/day of potable water are required for drinking and sanitation. At present water is trucked from Lüderitz to Elizabeth Bay, on a daily basis, by tankers which have been modified to cope with travelling over the rough terrain. The current water purchase and trucking option is extremely expensive and initial cost estimations indicated that the desalination of sea-water by RO could produce potable water at roughly half the cost.

The fortunate situation prevailed that the mine would act as a quasi-client for the water produced by the RO pilot plant. This, combined with the fact that the site had all the required prerequisites for the pilot study, resulted in the selection of Elizabeth Bay for the conduction of the experimental work of this project.

1.5 PILOT STUDY OBJECTIVES

The objectives of this pilot scale study of the desalination of sea-water by reverse osmosis are summarised in the following paragraphs:

1.5.1 TECHNICAL FEASIBILITY OF RO DESALINATION

It was desired to investigate and demonstrate the technical feasibility of sea-water desalination by RO along the West Coast of South Africa, being aware of the high levels of colloidal and biological matter in the water which were known to result in membrane fouling.

1.5.2 EVALUATION OF RO PRETREATMENT

The second objective was to evaluate and demonstrate the most suitable pretreatment regime which results in optimum RO performance. Special emphasis was placed on the use of tubular ultrafiltration with a locally manufactured system.

1.5.3 EVALUATION OF RO EQUIPMENT

Although the ability of RO to desalinate sea-water was known from the operation of large overseas plants, it was required to evaluate selected commercially available sea-water RO membranes under local conditions, especially in combination with ultrafiltration.

1.5.4 GAINING OF EXPERIENCE

It was intended to gain experience with regard to the operation and design of sea-water RO plants for future local construction.

SECTION TWO : EXPERIMENTAL EQUIPMENT AND SITE

A purpose-designed pilot plant was constructed by Membratek for DRL, to enable the investigation of sea-water desalination by reverse osmosis and to evaluate several pre-treatment techniques.

The entire plant was containerised to facilitate ease of transport and quick site establishment at remote locations. Plant operation was automated to a high degree with the aid of a PLC linked to a supervisory software package. This allowed data logging of various operating parameters at a frequency of once every four minutes. The data logging system and computer support software were designed and supplied by DRL.

The design capacity of the plant was 5 m^3/day with sea-water at a recovery of 30-35% and a feedwater temperature of 15 ^{0}C. A post-chlorination facility was provided for the production of potable water.

2.1 SEA-WATER INTAKE

Deep sea-wells are advantageous from an RO systems point of view as their water is usually very low in biological activity. Thus, little or no pretreatment is required to control biological activity. In contrast to sea-water from sea-wells, the biological activity of surface sea-water can be very high and pretreatment for biological control is mandatory. This is especially relevant for surface sea-water from the West Coast which is known for its high levels of nutrients and micro-organisms.

The geological formations on the West Coast do not offer natural prefiltration of sea-water in the form of sea-wells. Attempts to draw feedwater from sea-wells during the Swakopmund study failed because the wells could not sustain flow and collapsed easily. From sheer necessity the emphasis in this study had therefore to be placed on the proper pretreatment regime in order to ensure the successful operation of the RO system.

Sea-water for the pilot plant was obtained by tapping off from an existing sea-water line which supplied the ore sampling unit of the mine. This sea-water pipeline extended into the bay for approximately 60 metres from the shore on a previously constructed jetty. Submersible pumps were used to transfer sea-water from the bay to the ore sampling unit.

Elizabeth Bay is a natural bay on the West Coast of Namibia which is subjected to the cold Benghuela stream which originates from the Antarctic. Because of this, the water of the West Coast contains relatively high levels of plankton and nutrients. During calm conditions the bay is reasonably sheltered, but in stormy conditions with westerly winds the surface of the bay is extremely rough. The quality of the sea-water from the intake deteriorated tremendously in terms of turbidity and organic content on such occasions. Hence the successful conduction of RO pilot trials at this site, under these extreme conditions, should be able to demonstrate the capabilities of the process.

2.2 CONFIGURATION OF PILOT PLANT

2.2.1 MECHANICAL LINE DIAGRAM

A mechanical line diagram of the pilot unit is presented in Figure 2.1 and should be read in conjunction with the following process description:

2.2.2 FEED SECTION

Raw water from the sea-water intake was first passed through a 200 μm strainer for the removal plankton and suspended material. Pre-screened raw water was then collected in the 500 l PE storage tank TK1 which was fitted with a ball float valve for automatic shut-off at high level. Acid and biocide addition were effected by direct dosing into the tank. A mechanical stirrer MX1 was provided for proper mixing.

Raw water was then pumped by means of a centrifugal pump P101 (2,5 bar discharge) from TK1 through a heat exchanger HX1 and static mixer SM1 to the pretreatment section. The dosing of coagulant prior to the static mixer was possible. On-line turbidity and pH were recorded between pump P101 and the heat exchanger.

2.2.3 PRETREATMENT SECTION

The plant was configured to enable the evaluation of the following pretreatment equipment, either singularly or in combination:

a) dual media filtration
b) ultrafiltration
c) cartridge filtration
d) activated carbon treatment

Water from the feed section was normally routed to the dual media filter FL1 which consisted of sand and anthracite beds. Dual media filtrate could then be subjected to ultrafiltration. Alternatively, bypassing the dual media filter was possible.

The ultrafiltration unit consisted of 4 parallel MEMTUF trains, each train comprising 5 modules of 1 m length, blocked together and internally manifolded in a parallel fashion. Each module contained 40 tubes of 9 mm diameter with a 1x40 tube configuration. This provided a total membrane area of 20 m^2. The unit configuration was later changed in an effort to improve linear tube velocities and recovery. The ultrafiltration membranes were housed inside a 500 l PE tank which served to collect UF permeate and was used for level control purposes. A CIP system was provided in the form of a 200 l PE tank TK2 and a centrifugal pump P102. This pump was also used to transfer UF permeate to the activated carbon column FL3 or cartridge filters FL4 to FL7.

2.2.4 ACTIVATED CARBON AND CARTRIDGE FILTERS

An activated carbon column FL3 was provided for the purpose of removing chlorine from the feedwater prior to RO, because the RO membranes used in the trials were sensitive to chlorine. The presence of chlorine in the feedwater results in membrane degradation with a consequent decline in rejection capabilities. Again a bypass facility was fitted to enable operation without activated carbon treatment.

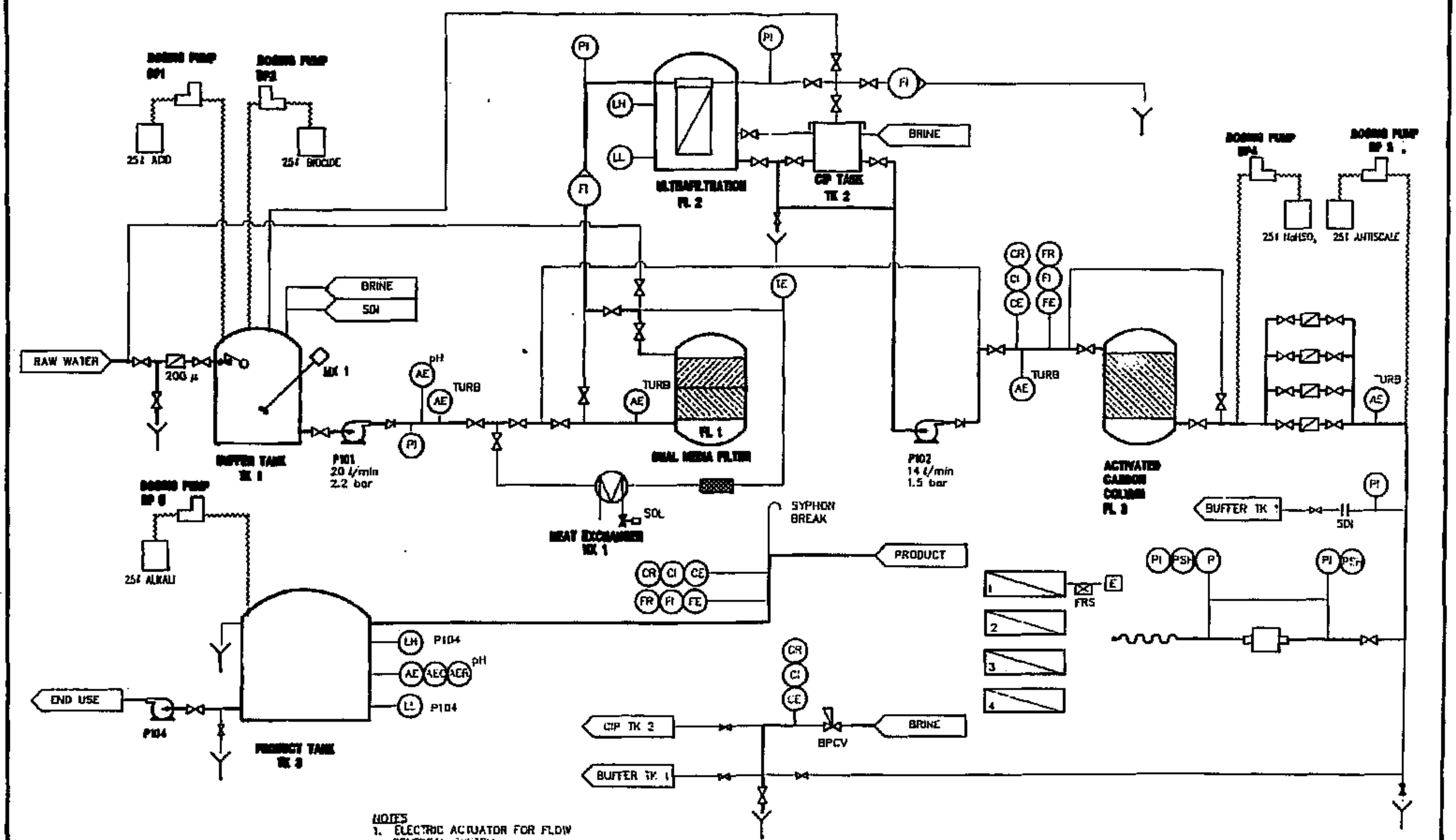
A cartridge filter bank containing elements of 5 micron was installed since this type of filtration is considered to be standard pretreatment to HFF and spiral-wound RO. The purpose of the cartridge filters was to remove suspended solids from the feedwater and carry-over from the carbon column which could block the flow channels of the RO permeators.

Antiscalant was dosed directly into the feedwater line immediately before the cartridge filters.

FIGURE 2.1 MECHANICAL LINE DIAGRAM FOR CONTAINERISED PILOT PLANT

See page 10a

MEMBRATEK (PTY) LTD PO BOX 7240 NOORDER PAARL 7623
DE BEERS RESEARCH LABORATORY-SEAWATER PILOT PLANT
MECHANICAL LINE DIAGRAM



NOTES
1. ELECTRIC ACTUATOR FOR FLOW REVERSAL SYSTEM
2. ALL PIPES AND FITTINGS, SS OR PVC/PP

RH 20|11|91

2.2.5 REVERSE OSMOSIS SECTION

The reverse osmosis section comprised a high pressure pump P103, RO permeators and back pressure control. A free chlorine probe was fitted before the high pressure pump to effect system shut-down in the event of chlorine breakthrough from the pretreatment section.

The high pressure pump was a positive displacement, diaphragm type unit, designed to eliminate the problems associated with plunger pumps. The unit was geared to deliver 14 l/min at 60 bar. High and low pressure switches were fitted on the discharge and suction sides of the pump to prevent operation at either excessive pressure or starvation, respectively.

Two types of RO membranes were investigated *viz.* DuPont B-10 aramid and Filmtec FT-30 SW. The DuPont membranes were configured as two model 6410T B-10 HFF permeators, connected in series, whereas the Filmtec equipment comprised four SW30-2540 elements in series. Technical details, as provided by the respective manufacturers, are given in Table 2.1.

2.2.6 PRODUCT SECTION

Product from the RO section was collected in a 200 l PE tank fitted with a pH probe and controller for the automatic dosing of NaOH by means of dosing pump DP5. Flow and conductivity transmitters were installed in the product line before the tank in order to record the product flowrate and conductivity. High and low level switches in the product tank activated the product transfer pump P104 in order to supply product to the point of use.

TABLE 2.1 PRODUCT SPECIFICATIONS OF SEA-WATER RO EQUIPMENT

DUPONT B-10 PERMEATOR - MODEL 6410T *(DuPont, 1990)*	
Membrane type	B-10 aramid
Membrane configuration	Hollow fine fibre
Initial product water capacity[1]	2,46 m³/day nominal
Salt rejection[1,2]	99,2 % nominal
Rated operating pressure[3,4]	5 515 - 8 274 kPa
Temperature range[4]	0-40 °C
pH range[4], continuous exposure	4-9
Maximum recommended feed SDI	3
Shell dimensions	15,5x11,75x58,7 cm (ODxIDxL)
Shell material	Filament-wound fibreglass epoxy

Notes:

[1]Based on operation with a feed of 35 000 mg/l NaCl, 6 895kPa, 25°C, 35% conversion
[2]Minimum 98,7%
[3]Rated operating pressure varies with feedwater temperature
[4]For operation outside this range consult DuPont

FILMTEC SW30-2540 ELEMENT *(Filmtec, 1984)*	
Membrane type	FT30 thin film composite
Membrane configuration	Spiral-wound
Initial product water capacity[1]	1,9 m^3/day nominal
Salt rejection[1,2]	99,1 % average
Maximum operating pressure[3]	6 800 kPa
Maximum operating temperature	45 ^{0}C
pH range, continuous exposure	2-11
Maximum feed SDI	5
Shell dimensions (approx.)	8x7x105 cm (ODxIDxL)
Shell material	Filament-wound fibreglass epoxy

Notes:

[1]Based on 35 000 ppm sea-water, 25^{0}C, pH8
[2]Minimum 98,6% of chlorides
[3]For operation outside this range consult Filmtec

2.3 PLANT CONTROL AND INSTRUMENTATION

The plant was fitted with a variety and large number of instruments for research purposes and to allow a high degree of automatic operation. Due to the remote location of the pilot study site it was impractical to have a skilled operator in attendance for extended times. Reasons for this were the unavailability of such a person and the cost implications involved.

Although not fully automated, the controls provided allowed unsupervised plant operation for periods of up to 16 hours, mainly overnight. During normal working hours mine personnel were available, on occasion, to refill dosing chemical containers and restart the plant after shut-down. Unfortunately the plant was unable to restart automatically after a power failure or trip condition. Since the plant relied on power supply from a trailer-mounted generator unit, frequent power trips were experienced. This resulted in a high percentage of down-time and substantially less running hours were accumulated than desired.

The minimum number of instruments were field-mounted, with most operating parameters being relayed to the central control panel and data logging system by means of transmitters which had to supply a 4-20 mA signal. Separate control loops were used for pH adjustment, chlorine dosing, bisulphate dosing and temperature control. Tank levels and pumps were controlled by relays.

A PC facility complete with supporting software for the collection and recording of operating parameters, such as flow rates, conductivity, temperature and turbidity, as a function of time was supplied by DRL.

2.4 CONSTRUCTION

The complete plant was housed in a standard container with dimensions of 6 x 2,4 x 2,6 m (LxWxH) which was modified to include lighting, ventilation, a window and air conditioning. The container concept proved indispensable during transportation, protection of equipment from the environment and ease of site establishment.

Metal corrosion was expected to be problematic due to the corrosive nature of sea-water and the salty atmosphere at the pilot study site. Premature failure of the RO system will result if corrosion is not controlled. The most effective way to minimise corrosion in an RO plant is to limit the use of metallic components.

Based on these considerations, non-metallic construction materials were used on all wetted parts where they wereconsidered to be practical and economical. Hence all low pressure plumbing was constructed from uPVC, using standard pipe and FIP type solvent-weld fittings. High pressure pipe runs were kept as short as possible. Fixed lines were assembled in 316 SS while extensive use was made of reinforced rubber flexibles for the interconnection of RO permeators and other equipment. The use of exotic materials e.g. nickel-copper alloys and titanium as would be used in large sea-water installations *(Herda and Jasner, 1989)* and 245 SMO austenitic stainless steels *(Avesta, 1985)* were not considered because of high cost and the relatively short duration of the study.

Pump heads were either manufactured from aluminium bronze or 316 SS. Polyethylene was used as a construction material for tanks and pressure vessels for the RO elements were made from GRP.

SECTION THREE : RESULTS AND DISCUSSION

3.1 SITE ESTABLISHMENT

The plant departed by road transport from DRL in Johannesburg on 24 August 1990 and arrived at Elizabeth Bay four days later. The following three days were used to position the plant and to connect the relevant utilities. Subsequent test runs, similar to normal commissioning, established the basic functioning of the various equipment. Cold commissioning had been performed previously after completion of construction in the workshop.

3.2 PRETREATMENT TESTS

The performance of RO systems and membrane life depend critically on both the design and efficiency of the pretreatment system, particularly in larger plants *(Walton, 1991)*. As such special emphasis was placed on the investigation of pretreatment regimes during the pilot study. The major aspects which were considered, are discussed in the following paragraphs:

3.2.1 BIOLOGICAL CONTROL

Biological matter can be problematic when the feedwater contains sufficient nutrients to sustain rapid growth of organisms inside the RO permeators. This is especially relevant to surface sea-waters which contain high levels of virtually all nutrients required for biological activity and which are furthermore abundant in micro-organisms. Biological growth will cause poor permeator performance. The biological activity must therefore be controlled during operation so that system water quality and quantity are not affected.

Because of this the pre-screened (200 μm) sea-water had to be treated chemically to destroy the organisms present and to prevent further biological activity. Three basic routes for the control of biological matter were available:

a) *CHLORINATION-DECHLORINATION.* Chlorine is the most commonly employed disinfectant. The effectiveness of chlorine is dependent on the concentration, pH and contact time. As such the optimisation of the chlorine disinfection system had to be performed on site.

   Aromatic, synthetic membrane materials, such as the ones used commercially in sea-water RO systems, are sensitive to halogens, e.g. chlorine and bromine, which react with the membrane resulting in an immediate increase in salt passage. Since sea-water contains approximately 65 mg/l Br^- as ion, HOBr and HOCl are formed during the chlorination step. In order to prevent membrane degradation the chlorinated sea-water had to be dechlorinated prior to the cartridge filters. This could be achieved with an activated carbon filter or the injection of sodium meta-bisulphite.

b) *BISULPHITE TREATMENT.* The advantage of adding sodium meta-bisulphite to the feedwater for the control of biological matter is that dechlorination is eliminated. The chemical is known to have no detrimental effect on the RO membranes.

c) *ULTRAVIOLET RADIATION.* Ultraviolet radiation has been shown to be effective in controlling biological growth in small RO systems *(Goodwyn, 1976)*. For practical reasons this option was not considered during the pilot study.

In order to investigate the first two alternatives, a train of equipment comprising TK1, dual media filter and 5 micron cartridge filters was employed. NaOCl or sodium meta-bisulphite was added to TK1 with the aid of dosing pump DP2 at pre-set levels. The pH in the tank was maintained at 6,9 by a pH controller which was coupled to an on-line pH probe on the discharge side of P101. Acid was dispensed directly into the tank with the aid of dosing pump DP1. In the case of chlorination, sodium meta-bisulphite was injected into the feedwater line prior to the cartridge filters. A free chlorine probe was used, after the cartridge filters, in conjunction with a controller to ensure that no chlorine breakthrough occurred.

Agar plate counts and turbidity measurements showed that the chlorination-dechlorination route proved to be more effective. Since the control loop for dechlorination with sodium meta-bisulphite appeared to be reliable, this option was used for the control of biological matter in all subsequent work. As a result the activated carbon column was never used.

3.2.2 FILTRATION TESTS

Different filter combinations comprising dual media filtration, cartridge filtration and ultrafiltration, were briefly evaluated. Two regimes were consequently investigated in more detail:

a) *DMF REGIME.* Dual medial filtration followed by cartridge filtration (5μm) were used in this case. Such a configuration, with the addition of coagulant, is considered as conventional pre-treatment for sea-water RO systems. In this case the coagulant was omitted. The reason for this was that the reaction of cationic polyelectrolytic coagulants with certain constituents of the feedwater has been reported to result in colloidal fouling of the membranes *(Du Pont, 1983)*.

b) *UF REGIME.* This treatment regime comprised dual media filtration, ultrafiltration and cartridge filtration (5 micron).

The effectiveness of pre-filtration was quantified through Silt Density Index (SDI) measurements. The SDI has been found to be the best method to measure colloidal concentrations. An excellent correlation has been obtained between the SDI and colloidal fouling in RO permeators *(Du Pont, 1983)*. Other methods, e.g. turbidity and particle counts, are unacceptable since their accuracy is dependent on the particle size and concentration. Recommended feedwater SDI values for the different RO permeators are given in Table 2.1.

Salient data with regard to SDI and turbidity values for the DMF and UF regimes is given in Table 3.1.

TABLE 3.1 SDI AND TURBIDITY DATA FOR DMF AND UF REGIMES

PARAMETER	DMF REGIME	UF REGIME
Sea-water SDI	>8	>8 often ∞
RO feed SDI	>3	0,5-0,7
Sea-water turbidity (NTU)	>4	>4 often >150
RO feed turbidity (NTU)	>0,5	0,09-0,2

It was found that the DMF regime was susceptible to changes in the raw sea-water quality. Pre-treated RO feedwater quality deteriorated during adverse weather conditions when the sea-water contained increased levels of suspended and biological matter. This seems logical since the dual media filter operates on the principle of deep bed filtration which relies on entrapment of suspended solids. The pre-treated RO feed SDI could not be reduced to below a value of 3 which is recommended for the DuPont B-10 permeators.

The filtrate quality from the UF regime was excellent with respect to SDI and turbidity values as can be seen from Table 3.1. The quality remained practically constant despite large variations in raw sea-water quality. This may be explained by the fact that UF works on the principle of size exclusion and that the UF membranes had a fixed pore size distribution. The membranes used in the pilot trials had a MMCO of 40 000 when tested on a PVP solution under standard conditions.

Based on these preliminary investigations the decision was made to employ the UF regime as pre-treatment to RO.

3.3 ULTRAFILTRATION PERFORMANCE

Automated pilot plant operation with chlorination-dechlorination and UF pre-treatment regimes was started on 3 September 1990.

3.3.1 UF FLUX DECLINE

During the initial design stages the possible use of UF as pre-treatment to RO was assigned a relatively low priority since it was believed that the UF membranes would foul relatively quickly. As a result no flowmeters and transmitters were installed on the UF feed and retentate lines. Subsequently no feed, retentate and calculated permeate flow rates could be logged during initial start-up, once the effectiveness of the UF pre-treatment regime had been established. Flux data for UF was therefore limited to manual measurements until the installation of flowmeters on 29 October 1990, approximately one month after start-up.

Following start-up the UF flux declined rapidly from approximately 110 to 65 LMH within a period of 72 hours. The flux subsequently levelled off to between 46 and 39 LMH during the period in which manual measurements were made. Although flux values of between 30 and 40 LMH were considered to be economical, it would have advantageous to be able to operate at double these flux rates. This was considered possible since initial flux values had been substantially higher.

3.3.2 ON-SITE MEMBRANE CLEANING EXPERIMENTS

The flux decline was attributed to fouling and operation at non-optimum flow velocities. External inspection of the unsupported UF tubes indicated that the membrane surface was coated with a foulant film which was visible through the tubes as a dark discolouration.

Chemical cleaning experiments were carried out on 30 October 1990 in an effort to remove the foulant and to restore membrane flux. Due to the lack of potable water, sea-water UF permeate was used for the making up of chemical cleaning solutions.

Several consecutive cleaning cycles were performed, details of which are given in Table 3.2. All of these failed to improve flux values.

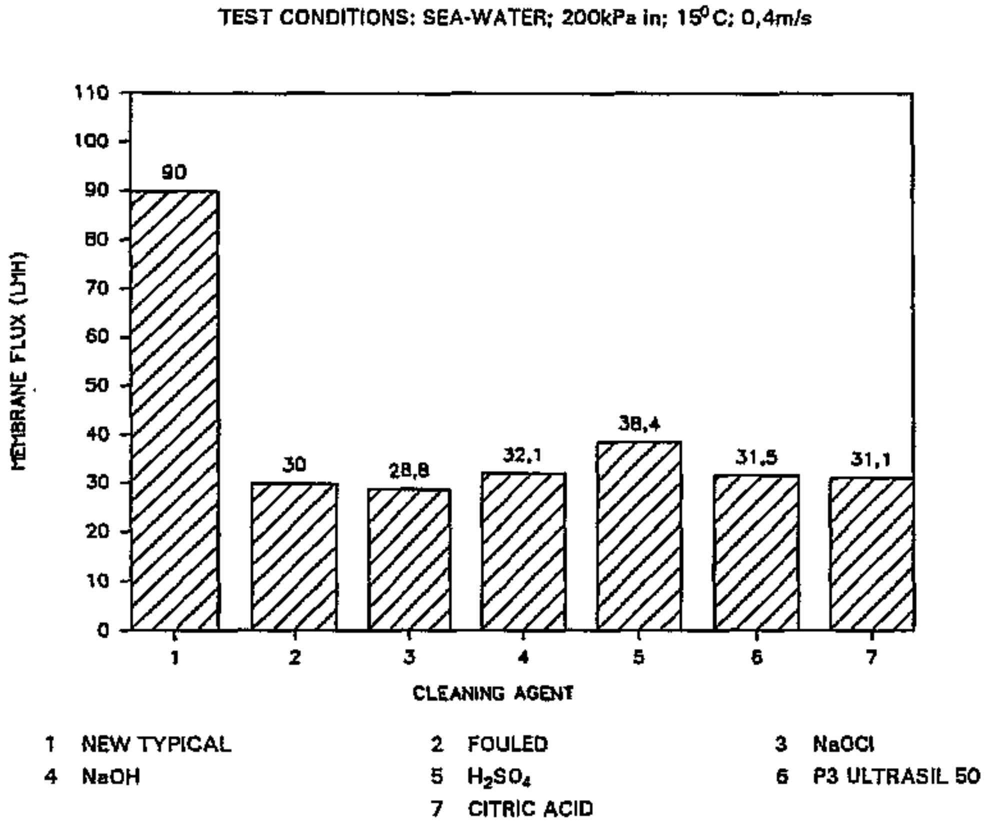
TABLE 3.2 PARTICULARS OF *INSITU* UF CLEANING AT ELIZABETH BAY

AGENT	CONDITIONS	DURATION
NaOCl	1 800 ppm; 15 °C	5 minutes
NaOH	Add to pH 10,5; 15 °C	30 minutes
H_2SO_4	Add to pH 1,9; 15 °C	10 minutes
P3 Ultrasil 50	0,8%; 15 °C	30 minutes
Citric acid	2%, pH4 with NH_3	45 minutes

These cleaning regimes were designed to remove both inorganic and organic foulants. P3 Ultrasil 50 is a commercially available cleaning agent by Henkel which is specifically formulated for the cleaning of RO and UF membranes which have been contaminated by proteins, fat and other food residues. It is obvious from the graphical representation in Figure 3.1 that these cleaning agents were unable to remove foulants from the membrane surface.

Earlier cleaning trials with a citric acid solution (2% mass/volume, corrected to pH 4 with ammonia) which is known to be effective in the removal of iron from the membranes, also showed no flux improvement.

FIGURE 3.1 EFFECT OF VARIOUS CLEANING TRIALS ON RESTORATION OF UF FLUX AT ELIZABETH BAY



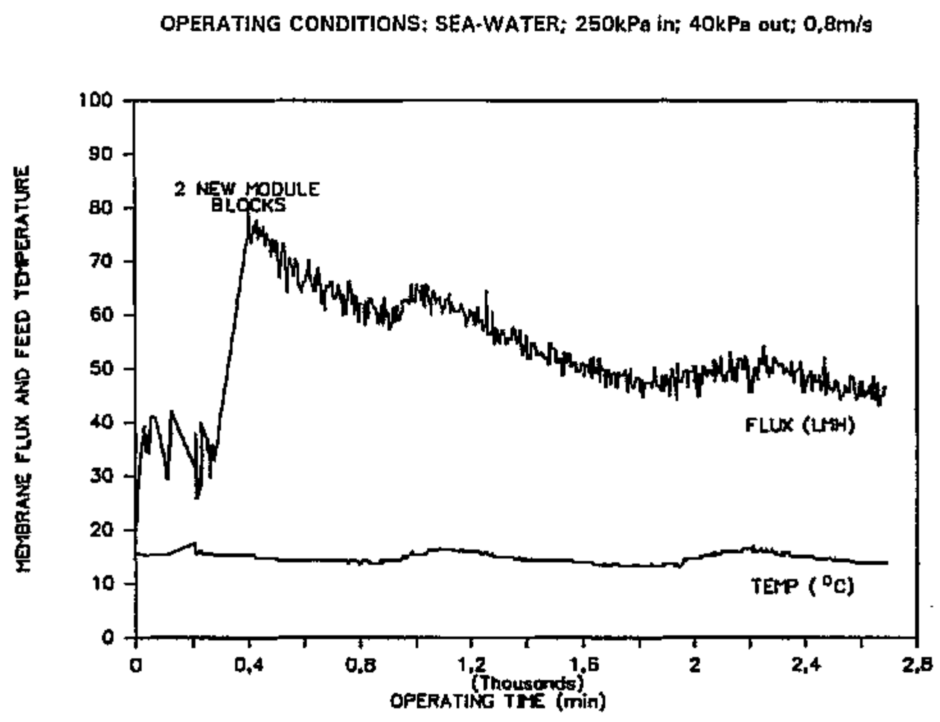
3.3.3 INSTALLATION OF NEW UF MEMBRANES

The reduced capacity of the UF system, which the cleaning trials failed to improve, threatened the continued operation of the RO section. because of low RO feed flow rates.

Two new MEMTUF blocks (half of the total membrane area) were installed after the cleaning experiments in an effort to increase the permeate flow from the UF section. The original configuration of 4 parallel trains, each with 5 modules connected in parallel, was changed to 2 parallel trains, each comprising 2 series blocks with each block containing 5 modules connected in parallel. With the given output of the sea-water feed pump, the initial configuration resulted in an effective inlet tube velocity of only 0,4 m/s. This was doubled with the adapted configuration and it was hoped that the increased linear tube velocity would have a beneficial effect on flux decline and recovery.

Flowmeters and transmitters were installed on the UF feed and retentate lines before conducting cleaning experiments. This allowed the recording of these flow rates and calculation of permeate flowrate on the data logging system. Initially the flux rate could be doubled with the replacement of half the membrane area with new membranes, as can be seen from Figure 3.2. The figure also shows the steady flux decline from approximately 75 LMH to the more stable value of about 45 LMH within the relatively short period of 2 400 minutes (40 hours). Fortunately the stabilised flux rate at 45 LMH was roughly 10 LMH higher than before the installation of the new membranes, which allowed the continued running of the RO section.

FIGURE 3.2 PLOT OF ULTRAFILTRATION FLUX AND FEEDWATER TEMPERATURE AGAINST OPERATING TIME



It was nevertheless obvious that fouling of the UF membranes remained problematic, although the flux rates seemed to stabilise at about half the initial value. If the initial flux values could be maintained over the long term, only half the membrane area would be required for a given system capacity, translating to a substantially reduced system cost. In order to achieve this a method for the removal of the membrane foulant had to be found. Only then could ways to prevent the fouling be engineered.

The fouled modules that were removed from the UF system were taken back to the laboratory to further investigate this matter.

3.4 LABORATORY INVESTIGATIONS

3.4.1 BEAKER EXPERIMENTS

Small sections of tubes with fouled membranes were immersed in beakers containing a variety of cleaning solutions during initial experiments.

In order to confirm the results which were obtained during the *insitu* cleaning of the modules at Elizabeth Bay, the cleaning regimes given in Table 3.2, including citric acid buffered to pH 4 with ammonia, were repeated. Again, these were unable to remove significant amounts of foulant.

3.4.2 ULTRASONIC CLEANING

Dissection of the membrane tubes and visual inspection of the membrane surface, revealed that the foulant was a slimy layer which was seemingly easily removed by mechanical means when wet. Subsequent treatment of tube sections in an ultrasonic bath confirmed this. The foulant layer was removed from the membrane surface within minutes. This process was enhanced with the simultaneous use of a surfactant, e.g. Biotex with enzymatic action. Cleaning was found to be extremely difficult once the layer had been allowed to dry.

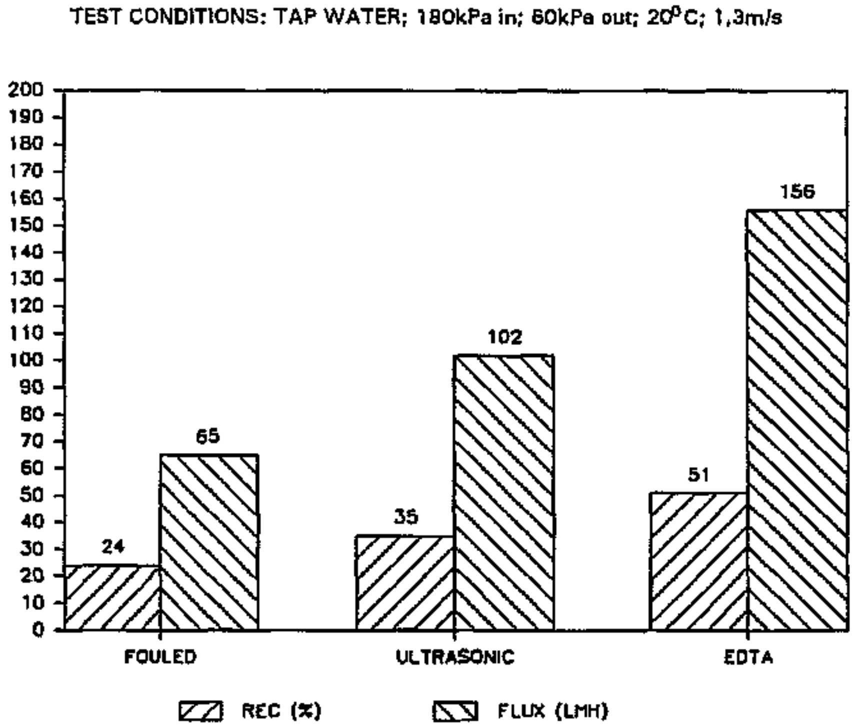
The cleaning of a complete module was attempted in a large ultrasonic bath. Unfortunately the bath was not large enough to accommodate a complete module and had insufficient energy input to clean the membrane surface completely. Nevertheless a substantial flux increase was obtained, as may be seen from Figure 3.3.

The use of ultrasonics was perceived as a viable means to prevent fouling, but the energy levels required for effective cleaning on large UF systems were considered to be excessive. The cost of high powered ultrasonic generators was furthermore thought to be too high to be sustained by a low-cost pretreatment system such as the MEMTUF unit.

3.4.3 CHEMICAL CLEANING

Following suggestions from the literature *(DuPont, 1983)* which were known to be effective in the removal of biofilms from RO membranes, an EDTA solution was tried for the removal of the UF membrane foulant. Optimum cleaning conditions were found to be 0,2% EDTA (approximate pH of 5) raised to a pH of 11,5 with NaOH. This solution resulted in complete foulant removal from the MEMTUF module within three minutes. The subsequent water flux that was obtained, is shown in Figure 3.3.

FIGURE 3.3 FLUX VALUES FOR MODULE CLEANING ATTEMPTS PERFORMED IN THE LABORATORY



3.4.4 NATURE OF FOULANT

The foulant was examined with the aid of SEM, EDAX and standard wet chemistry analytical methods. Of these the microscopic analysis yielded the best results.

The thickness of the foulant layer was shown by SEM to range between 5-20 micron consisting of fine particles with a size of >2 μm. EDAX showed silica, aluminium, oxygen and iron as the predominant elements with relatively little carbon. It followed that the foulant was mostly of inorganic nature and refractory, as confirmed by the wet chemistry analysis which reported the presence of clay.

Closer inspection by SEM also revealed small plates, with regularly spaced holes, in the fouling layer. These plates contained carbon and calcium and were most likely the skeletal remains of small organisms such as diatoms. This explains the ineffectiveness of the chemical cleaning regimes with the exception of the EDTA/NaOH combination.

3.4.5 SPONGE BALL CLEANING

The results of the above experiments established that chemical cleaning was possible and that mechanical cleaning with ultrasonics seemed feasible, although expensive.

Due to the construction of the MEMTUF system, with its unsupported tubular configuration, frequent chemical cleaning is not desired, because of the detrimental effect on tube strength

(Barnard, 1991 and Strohwald, 1991). The long-term effect of ultrasonic cleaning on the integrity of the weld-seam and the polyester backing tube were unknown. Tubular UF membranes are produced by fusion of the overlapping edges of a flat polyester strip which is wound around a mandril in a helical fashion *(Strohwald, 1988).* Since the burst strength of the tubes in the MEMTUF module relies on the strength of the weld-seam, any operational factor affecting the weld-seam will influence the mechanical reliability of the module.

Another means of removing the foulant was desired, preferably mechanical in nature, in order to prevent the undesired effects that chemical cleaning has on the integrity of the tubes. The use of sponge balls immediately sprang to mind since these are used extensively in tubular RO systems for the removal of surface deposits. Unfortunately, the internal parallel configuration of the MEMTUF unit does not provide a continuous flow path, which is required for sponge ball cleaning. Nevertheless a module block was dismantled and a single module was subjected to sponge ball cleaning to observe the effect.

The pure water flux values for a fouled module before and after sponge ball cleaning are given in Table 3.3. No chemical additives, e.g. surfactants were used. The conditions used for the determination of flux are those for pure water flux which are employed during the evaluation of UF membranes after manufacturing. The pure water flux figure of the sponge balled module corresponded with that of a new membrane.

TABLE 3.3 EFFECT OF SPONGE BALL CLEANING ON FLUX RESTORATION OF FOULED UF MODULE

CONDITION	FLUX (LMH)
Fouled module	91,8
Sponge ball (2x)	257,4
Test conditions: ROTAP, 200kPa inlet pressure, 15°C, 1m/s tube velocity	

These promising results inspired additional work at Elizabeth Bay with modified TUF modules, using 12,5 mm diameter tubes having a continuous flow path. These modules had the ability to be cleaned by sponge balls.

3.4.6 SWUF MODULES

Short-term tests were performed at Elizabeth Bay with modified TUF modules to test the sponge ball cleaning concept. Two of these modules were temporarily installed in the place of the MEMTUF unit and run for a period of about 72 hours.

With half-hourly sponge ball cleaning, effected with the use of sponge ball traps and a flow reversal system, the flux could be maintained between 90 and 95 LMH, using operating conditions similar to the MEMTUF unit. The beneficial effect of the sponge balls becomes apparent when the flux decline from 80 to 50 LMH within 40 hours is compared with that of operation without sponge ball cleaning (refer Figure 3.2). Unfortunately the need for the removal of the plant from site, due to security implications with the imminent start-up of mining operations, prevented extended experiments in this respect.

The concept of the modified TUF modules, combined with sponge ball cleaning, for the specific pretreatment of sea-water prior to RO was identified as a future in-house development project. Such modules subsequently became known as SWUF (Sea-water Ultrafiltration) modules.

3.5 REVERSE OSMOSIS PERFORMANCE

The use and efficiency of HFF RO permeators have always depended on the performance of the pretreatment system. Conventional sea-water pretreatment systems are sometimes incapable of producing RO feedwater of sufficient quality for use with HFF systems. Because of this the spiral-wound configuration is often favoured in applications where the fouling potential is higher. Nevertheless HFF systems have shown an increase in the market share over spiral systems. Today about 70% of the world's installations use HFF permeators *(Ahmed and Moch, 1991)*. This is attributed to the following major factors:

a) *HIGH VOLUME EFFICIENCY.* HFF permeators show 60% more product flow on average per unit vessel volume than the spiral-wound equivalent due to their high packing density. This is despite the fact that HFF permeators have a lower flux rate per unit membrane area.

b) *HIGH PRESSURE CAPABILITY.* HFF systems can be operated at higher pressures than their spiral counterparts. This translates to higher recoveries and lower system cost.

c) *LONG MEMBRANE AND STORAGE LIFE.* Aramid HFF membranes allow post-treatment for the restoration of rejection capability, resulting in extended membrane life. The permeator is stored as a complete leak-proof unit which eliminates membrane deterioration due to drying or loss of preservative during storage.

Since the effectiveness of the UF pretreatment regime had been demonstrated, efforts with regard to the evaluation of the two RO systems were concentrated on the HFF permeators.

Due to a variety of factors, e.g. power failures, manual start-up and lack of manpower, which were mentioned previously (refer Section 2.3) a total of only 350 hours could be logged on the RO section in the 3 month trial period.

3.5.1 SCALE CONTROL

Scaling in RO systems is caused by the precipitation of sparingly soluble salts. The scaling potential of any feedwater is determined by the chemical composition of the water, the conversion of the RO system and the solubility limits of the various salts. Calcium carbonate is usually the only salt in sea-water for which pretreatment is required. B-10 permeators can operate at conversions up to about 40% with sea-water without usually exceeding the solubilities of $CaSO_4$, $BaSO_4$, $SrSO_4$, CaF_2, and SiO_2.

The solubility limits of $CaCO_3$ are not well defined for sea-water. Typical surface sea-water has a total alkalinity of approximately 120 mg/l (as $CaCO_3$) with a pH of about 8,2. The criteria used to determine the need for $CaCO_3$ scale control is the Stiff and Davies Stability Index (S&DSI) of the brine stream. This is estimated from the feedwater analysis, the conversion of the RO system and the rejection of the various ions by the B-10 membrane. If the S&DSI is negative, the $CaCO_3$ will tend to dissolve. Alternatively, if the S&DSI is positive, $CaCO_3$ will tend to precipitate. Since preliminary calculations indicated that positive S&DSI values could be expected during the operation of the pilot plant at the desired conversion of 30-35%, provision was made for scale control.

Sulphuric acid is often used to obtain a negative S&DSI in the brine stream. Hydrochloric acid may also be used, but it is more difficult to handle and more expensive. Another possibility for scale control is the addition of scale inhibitors. The effectiveness of a particular scale inhibitor is best evaluated during actual operation with a specific feedwater at the desired operating conditions. Since only a limited amount of work has been performed with regard to the effectiveness of these chemicals in RO systems, the decision was made to use this option for scale control during the pilot study.

When using an inhibitor various factors must be considered:

a) Chemical compatibility with membranes;
b) efficacy (with positive S&DSI);
c) toxicity with respect to handling, potable water and brine disposal;
d) pollution (disposal of brine)
e) cost.

The ultimate selection of scale inhibitor for the pilot study fell on Belros 285, a Ciba-Geigy product especially developed for this purpose, which was dosed in-line before the cartridge filters at concentration of 10 mg/l product in the feed stream. This was more than the recommended 2-5 mg/l product. The higher dosing rate was chosen to ensure a margin of safety.

The effectiveness of the inhibitor was indicated by the following parameters, which indicate membrane fouling by $CaCO_3$ scale:

a) A decrease in product flow at constant pressure;
b) an increase in differential pressure across the permeators;
c) a decrease in salt rejection of the membranes.

It follows from the results presented in the subsequent paragraphs that none of these effects were apparent. The use of scale inhibitor was therefore successful, especially since conversions in excess or 40% were experienced on occasions (refer Figure 3.6).

3.5.2 RO PRODUCT FLOW RATES

The two B-10 HFF permeators delivered product at an average rate of 4,0 l/min during the test period. This translates to a product output of 5,76 m^3/day which is substantially higher than the specified 4,92 m^3/day (2,46 m^3/day per permeator, refer Table 2.1). A plot of product flowrate and feedwater temperature against operating time is presented in Figure 3.4. These product flow rates were achieved at the relatively low pressure of about 50 bar. The product flow rates remained relatively stable with variations being attributed to changes in feed pressure, feed flow and temperature. Fouling, as indicated by a gradual pressure increase, was not experienced.

3.5.3 RO MEMBRANE SALT REJECTION AND PRODUCT QUALITY

The dechlorination regime with $NaHSO_3$ worked extremely well and no chlorine breakthrough was experienced. As a result the rejection capabilities were unaffected. The average rejection, based on conductivity measurements, for the duration of the test period was 99,04% with a standard deviation of 0,16% and respective minimum and maximum of 98,04% and 99,47%. The variation in rejection with time is illustrated in Figure 3.5.

The practically constant rejection values reflect the absence of membrane fouling by colloidal and biological matter, as well as scaling by $CaCO_3$. This is attributed to the efficacy of the pretreatment regime that was used.

With a feedwater conductivity in the region of 47 000 μS/cm these rejections resulted in a product water conductivity of 452 μS/cm on average. The high quality of the product is apparent when one bears in mind that this is within the *recommended* limits of the SABS *(1984)* specification for domestic water supplies.

FIGURE 3.4 **PLOT OF PRODUCT FLOW AND FEED TEMPERATURE AGAINST TIME FOR B-10 PERMEATORS**

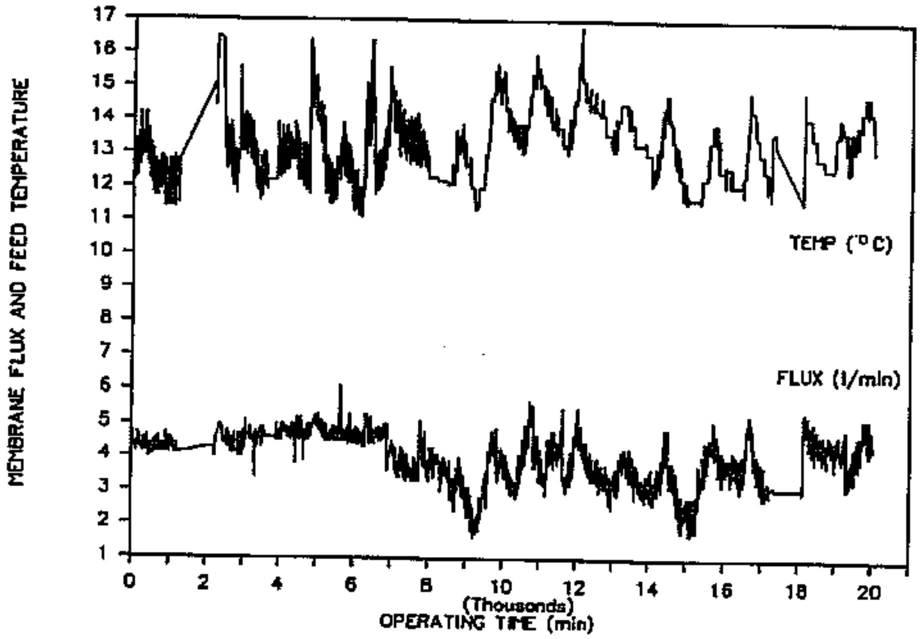
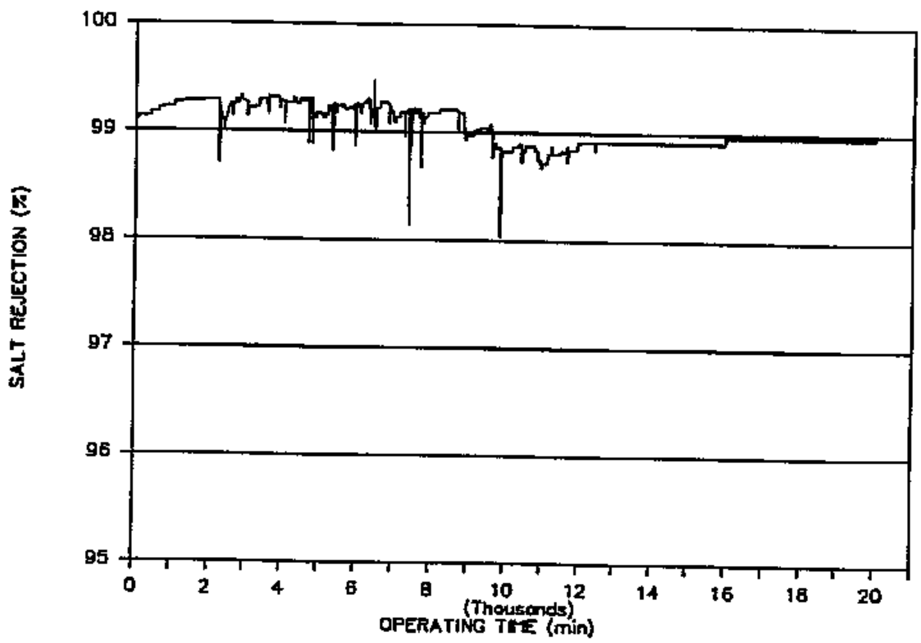


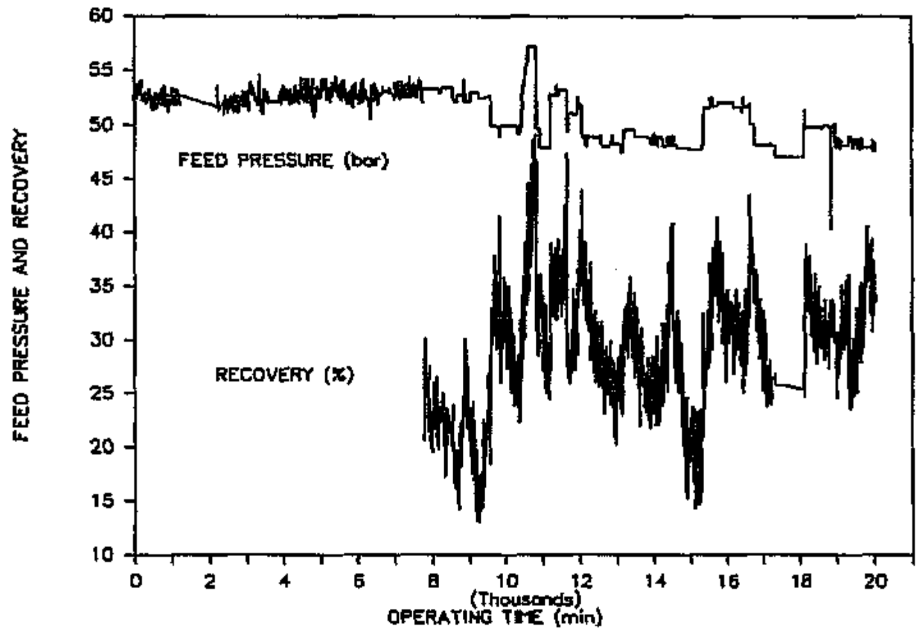
FIGURE 3.5 **PLOT OF SALT REJECTION AGAINST TIME FOR B-10 PERMEATORS**



3.5.4 RO OPERATING PRESSURE AND RECOVERY

Since the RO system operated with a manual back pressure control, set at a fixed pressure, the recovery varied with feedwater temperature and feed flowrate. Since point readings were transmitted by the feed and brine flowmeters some peaks and valleys were experienced in the data presented in Figure 3.6, although efforts were made to normalise the data.

FIGURE 3.6 PLOT OF FEED PRESSURE AND RECOVERY AGAINST TIME FOR B-10 PERMEATORS



It follows that the feed pressure remained relatively constant between 50 and 55 bar. A gradual pressure increase, indicative of membrane fouling, was not experienced. The average recovery (conversion) during the test period was approximately 30%, although higher recoveries of 45% and more were obtained on occasions. The use of Belros 285 as a scale inhibitor proved successful in the sense that no $CaCO_3$ scaling was experienced at these recoveries, as would have been reflected by a decline in product flowrate and salt rejection.

SECTION FOUR : CONCLUSIONS AND RECOMMENDATIONS

4.1 CONCLUSIONS

It is concluded that the original project objectives were achieved. The following conclusions may be drawn from the results which were obtained from the pilot study:

4.1.1 TECHNICAL FEASIBILITY OF RO DESALINATION

The technical feasibility of sea-water desalination by RO to produce water of potable quality was demonstrated over a 350 hour period of continuous operation. Product water with an average conductivity of 452 μS/cm was delivered, which is within the recommended limits of the SABS specification for domestic supplies.

4.1.2 EVALUATION OF RO PRETREATMENT

It was shown that tubular ultrafiltration, in combination with dual media and cartridge filtration, was capable of producing RO feedwater of acceptable quality on a continuous basis. Conventional pretreatment in the form of coagulation, dual media and cartridge filtration could not provide RO feedwater of acceptable quality, especially when the raw sea-water quality decreased due to stormy weather. The filtrate quality from the UF pretreatment regime was unaffected by the quality of the raw sea-water.

Ultrafiltration flux declined rapidly to about half the initial value due to fouling. Stabilised flux values of 40-45 LMH were considered to be economical, although operation at the higher initial levels of 90-100 LMH would be far more economical. Mechanical cleaning of the tubular membranes with sponge balls proved possible. It was shown that with the use of sponge balls and flow reversal, flux values could be maintained at 90-95 LMH.

4.1.3 EVALUATION OF RO EQUIPMENT

Because of the associated advantages, efforts were concentrated on the evaluation of HFF membranes, particularly since a pretreatment regime was available which could produce RO feedwater of excellent quality. This allowed full utilisation of the HFF system. The production of potable water of excellent quality was demonstrated with a single stage configuration. No appreciable membrane fouling was observed.

4.1.4 GAINING OF EXPERIENCE

Substantial experience was gained in the operation of a sea-water RO desalination system. Of particular importance is the information obtained about the use of ultrafiltration as pretreatment and future efforts should be directed towards the refinement of this technique.

4.2 RECOMMENDATIONS

The major success of the project lay in the fact that the need for proper pretreatment of RO feedwater during the desalination of sea-water was demonstrated. The use of locally developed ultrafiltration technology seemed particularly promising.

It is therefore recommended that the SWUF concept of RO feedwater pretreatment, in the desalination of sea-water, be investigated further to determine the cost aspects. The use of high-cost ultrafiltration systems have been shown to be economically attractive in this application *(Ericsson and Hallmans, 1991)* and the use of locally manufactured UF technology should therefore be more viable.

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