PRACTICAL EXPERIENCE IN DESIGNING AND OPERATING SEA WATER REVERSE OSMOSIS DESALINATION PLANTS ON THE ISLAND OF SEYCHELLES

Alan Joseph Sarkis

Biwater (Pty) Ltd, 10 Vervoer Street, Kya Sand, Randburg, Johannesburg. PO Box: 2216, Honeydew, 2040. Tel: 0027 11 549-7600. Fax: 0027 11 462 6267. E-mail: alan@biwater.co.za
Website: www.biwater.com

ABSTRACT

As water sources and population outstrips readily available water supplies, man is forced to seek other sources of drinking water. The treatment of seawater to produce drinking water is a well established process that has been around since the early 1970's. However, there are a number of pifalls to the uninitiated. Recent experiences on the Island of Seychelles where four Reverse Osmosis desalination plants have been built, have highlighted some important issues. We briefly discuss the topics of intake design and location, seawater quality, fouling, pilot plant studies and operating costs.

Keywords: Membranes, fouling, operating costs, experience, seawater reverse osmosis (SWRO)

INTRODUCTION

Seawater Reverse osmosis (SWRO) technology was development some 40 years ago, with desalination of seawater by reverse osmosis membranes implemented as a practical and economical option to provide drinking water in the 1970's. Originally the purpose for reverse osmosis was in seawater desalination applications as an alternative technology to distillation, which is very energy demanding. With the progress of space race, NASA invested heavily into the technology as the solution for providing drinkable portable water for space flight. Today, aboard the space shuttle, Reverse Osmosis forms a critical component to recycle wastewater including human fluid discharge.

In early 70s, the first commercial low pressure semi-permeable membrane was developed. It was capable of producing 1 to 5 gallons per day of clean, safe drinking water for small households. Initially water produced by SWRO was more than 3 times more expensive than water produced by conventional treatment facilities. However in the past 20 years, the cost of membranes has been reduced to an extent that membrane plants can compete with conventional treatment, in certain conditions. When water scarcity, raw water quality and removal rate of pathogens are important, membrane processes are a viable solution. If water collected by conventional means, either rainwater runoff and ground water supplies are insufficient, potable water produced by seawater desalination is the next best solution. If raw water quality is poor or variable, membranes provide a better treated water quality than conventional means. Finally, if more than one barriers is required to limit the risk of pathogen breakthrough, membranes are included as an additional barrier.

PROJECT BACKGROUND

The population of Mahe (the largest island of Seychelles) is supplied with water derived from small streams. Due to the steep topography and low retention capacity of the soil, the flow from the streams is erratic and falls to very low levels during the dry season. The island has only one major water catchment dam (Rochon Dam- 50,000kl) and a few smaller reservoirs.

Seychelles is a typical Indian Ocean Island where the demand for drinking water from its dams has outstripped the available supply. The need to increase water supply to the island, was recognised as far back as 1959. The increase in population and hence economic development, particularly in the tourism and agricultural sectors, has been responsible for the increase in demand. The Seychelles climate provides abundant rain between November and March. However, from April to October, a dry period persists to a point where the existing supply from dams and reservoir's becomes inadequate.

In order to meet the anticipated future water demand, a number of alternatives were investigated. These include the building of another catchment dam, improving rainwater collection, fresh water lagoons and reverse osmosis. Reverse osmosis was found to be the most economical solution.

Four RO plants were built to meet the present and future needs of 3 different islands. Two plants were built on the Island of Mahe, one the island of Praslin and one on La Digue.

BASIC DESIGN CRITERIA

All four plants are designed with the same basic process flow train. The capacities of each facility, together with main design parameters, are listed in Table 1.

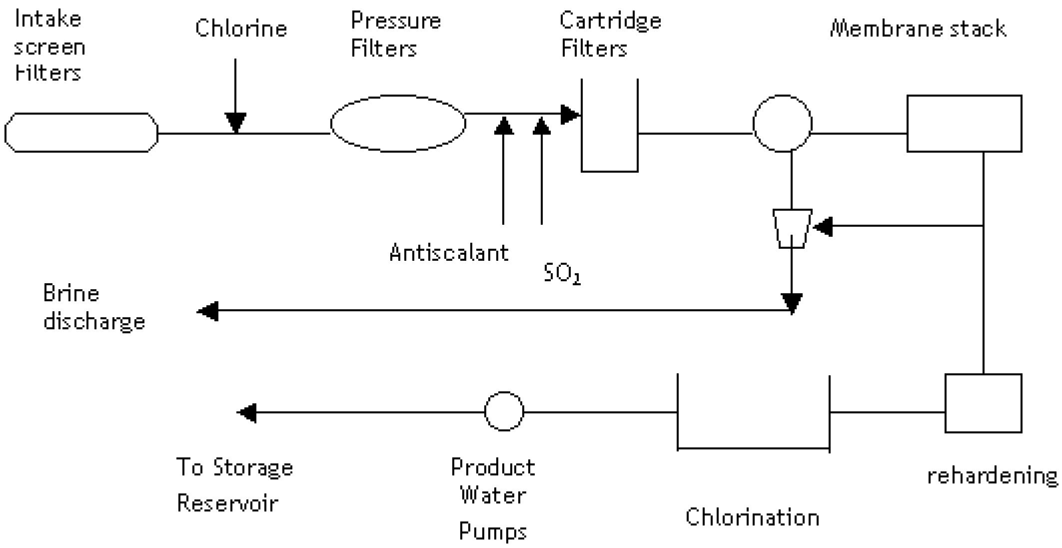

Figure 1. Basic process train.

Table 1. Basic design parameters.

Design parameter	**Value**
Capacity	Victoria - 5000 m³/day West Coast - 2500 m³/day Praslin - 600 m³/day La Digue - 300 m³/day
Recovery rate	Victoria – 45% West Coast - 40% Praslin - 40% La digue - 40%
Salt rejection	99.5%
Turbine efficiency	80%
Type of energy recovery turbine	Pelton wheel
Type of membrane	Spiral wound
Size	8 inch diameter
Make	Film Tech SW30HR-380
Vessels manufacturer	Codeline
No of elements per vessel	7
Operating period	Dry season only
Design operating pressure	65 bar (West Coast)
Actual operating pressure	59 bar (West Coast)
rehardening	Limestone

RAW WATER QUALITY

The design of the membrane stack assumed the following raw seawater quality, shown in table 2 below. Measured valves (*) refer to data collected during the detail design phase of the Contract.

Table 2. Raw water quality.

Ion	Unit	Tender value	Measured value (*)
Calcium	mg/l	410	441
Magnesium	mg/l	1370	1283
Sodium	mg/l	11100	10645
Potassium	mg/l	400	334
Bicarbonate	mg/l	144	123
Sulphate	mg/l	3110	3233
Chloride	mg/l	19850	20250
Nitrate	mg/l	2	Not measured
pH		8	7.9
Temperature	°C	25	26 to 32
TDS	mg/l	36390	37017

TREATED WATER QUALITY

Treated water quality exceeds expectations with a TDS of well below 500mg/l as per the Contract specifications.

Table 3. Treated water quality.

Parameter	Unit	Value
TDS	mg/l	220 to 320
pH		9.2
Sodium	mg/l	94
Chlorides	mg/l	150 to 210

INTAKE DESIGN

Three types of intake systems are commonly considered, when designing an intake structure. These alternatives are open intakes, beach well intakes and a buried pipe lattice intakes. The selection of an intake system and location of the intake structure is dependant on a number of key factors which all have to be carefully considered before finalising the design.

These factors are:

- Sand permeability
- Depth of sand to rock sea bed
- Type of sea life covering the sea bed
- Extent of coral reefs in the vicinity of the intake pipe
- Method of securing the intake pipe to the sea bed
- Depth of water at the intake screen
- Surf conditions throughout the year
- Shortest distance between plant area and suitable point of intake and brine discharge
- Raw water quality

A beachwell is usually the preferred option as it provides the best water quality. A well with a perforated PVC sleeve is sunk into the beach sand, at a suitable location.

Seawater seeps into this well and is then abstracted using a borehole pump. In this way, the raw seawater is filtered twice, first as is passes through the sea sand on its way into the beach well and then as it passes through the pressure sand filters.

When a beach wells system is not viable, the next alternative to consider is an open intake. A lattice type of intake depends on the permeability of beach sand, hence it is also not a viable option when sand permeability is low. An open intake screen should be located as close to shore as possible in a water depth of at least 10 meters. The reason for a minimum water depth is to reduce the amount of suspended solid material drawn in from the water surface and seabed.

Seychelles is a volcanic island, surrounded by coral reefs and shallow water. When the shallow water extends for long distances from the shoreline, the intake pipe has to be installed along this shallow reef until it reaches the deep water. Many volcanic islands in the Indian Ocean have a shallow coral reef surrounding the island, up to 6 kilometres long. Figure 2 depicts a typical Seychelles beach profile. This type of intake arrangement is obviously expensive and has severe impacts on the coral reef. Also note that it can be a lengthy procedure to obtain approval for an EIA study, as there will be a debate around the environmental impact versus the developmental benefits.

Raw water quality may be affected by the surf conditions, rivers outlets, sewage plant outfalls, and dump sites in close proximity to the point of intake.

Figure 2. Typical shoreline view in Seychelles.

The initial design assumed a beachwell structures for all four plants. However, the sand permeability was found to be too low for a beachwell. The design was then changed to an open intake system.

BRINE DISPOSAL

Returning of brine into the sea, without dilution, may cause a rise in local salinity. This may lead to a change in the biological functioning of the local ecosystem. Ideally, one looks for a disposal point where the brine is diluted sufficiently to minimise the change in salinity. One should carefully consider the plant location, taking into account the point of intake as well as the position of discharge.

LAYOUT OF INTAKE AND BRINE DISPOSAL SYSTEMS

Victoria SWRO Plant

Intake of this facility is located 150 m from the shoreline. The surf is calm most of the year round because the bay is protected from monsoon winds. The intake screen is positioned at a point where the coral shelf dips down as a result of dredging activities. Mean sea level is 2.8 meters above the intake screen and 2 meters off the sandy sea bed. Mean low water spring tide level is 2.1 meters above the intake screen. Raw water quality is good.

The intake is located 200 meters from a sewage works and an official dumpsite. Initially, there was a concern that the raw water may contain contaminants from these adjacent sites. However, no adverse affects on the raw water quality were found.

Brine is discharged into a pipe which runs about 200 meters away from the plant, into a concrete spillway and then into a harbour area. The water in the harbour area is slightly polluted by commercial and leisure crafts, hence the brine does not adversely affect the sea life in that area.

West Coast SWRO Plant

The intake system consists of a screen, an intake pipe, a pump station and a transfer line from the pump station to the plant. The Johnson's screen is positioned 100 meters offshore in a small bay. It is connected to a pump station, built into the beach. A HDPE pipe is installed next to the road and makes its way 800 meters along the road to the plant site. The installation of this pipe was tricky as the only available route was a furrow next to a winding road. The intake screen is 2.5 meters above mean sea level a and 2.2 meters above mean low water spring tide level.

Four months after the intake pipe was installed, the South East Monsoon winds shifted this buried pipe. Initially this pipe was secured with concrete anchor blocks and covered with beach sand. During the monsoon period, the surf becomes rough with the side currents washing away the sand that initially covered the pipe. These strong currents were then able to shift and bend the pipe, creating unnatural stresses on the pipe. Additional concrete anchors were used to secure the pipe in position.

Brine is discharged into a small stream that passes the treatment site. The flow of the stream is large compared to the flow of brine, so that dilution is sufficient.

Figure 3. Brine disposal at West Coast.

Praslin SWRO Plant

The intake is installed in a small bay, close to a man made jetty. Mean sea level is 4.3 meters above the screen and 3.8 meters above mean low water spring tide level.

Brine is discharged back into the bay area, 100 metres from the point of abstraction.

La Digue

The intake is situated in a harbour area where leisure boats churn up silts as they pass by the intake area. There is a risk of oil and fuel contamination from these boats. The intake structure was therefore carefully positioned, taking into account the aforementioned factors. Mean sea level is

2.5 meters above the screen and 2.0 meters above mean low water spring tide level. No problems have been encountered with the quality of raw seawater.

Brine is discharged into a 1 metre wide channel, which flows back into the sea. Dilution of the brine stream is large as it flows back into this harbour area. Refer to Figure 4 depicting the brine discharge channel.

Figure 4. La Digue brine discharge.

PRESSURE FILTERS

Single media sand filters are used to reduce the suspended solids in the raw seawater to a SDI of less than 3. No coagulant or coagulant aids are added.

Size of media	– 16/36 sands
Media depth	– 900 mm
Filtration rate	– 7 to 11 m/hr upflow velocity
Backwash	– 26 m/hr
Air scour	– 56 m/hr

TASTE OF TREATED WATER

Permeate produced by RO Plant may have a different taste to water produced by conventional methods. It is advisable to educate the public about RO plants and water quality issues relating to this type of facility. Initially Biwater received many complaints about the taste of this new supply, wherein it was assumed that the supply was inferior to the existing supply. After a lengthy investigation, Biwater managed to convince the Local Water Authorities and the public that the new water supply was indeed safe and that the slightly different taste of the water was no cause for alarm.

FOULING

Biological fouling can be controlled with a variety of oxidants such as chlorine. There is still much debate about the most effective fouling program.

Initially these new RO Plants in Seychelles were designed to provide chlorine at the intake screen and the sand filters inlet. Dosing at the intake screen was intermittent, applied as a shock dose once a week. Dosing at the filters inlet was designed as a continuous dose. During the construction phase of the project, new information regarding biofouling came to light.

It has long been standard practice to control biological growth in the feed water by the use of chlorine, in the pre-treatment stage. However, latest theories and practical experience suggest that it is not always successful in controlling biofouling (3). In fact, it has been found to worsen the biofouling potential. Significant improvements in DuPont hollow fibre RO plant performance has been reported after chlorine use was discontinued in a the Mediterranean sea water plant (4). In this case, cleaning frequency was reduced from biweekly to yearly.

The apparent reasons for this improvement are not completely clear, probably there are several contributing factors:

- It is know that some bacteria survive the disinfection process protected by extracellular polysaccharides (EPS) or as part of a planktonic community. The EPS could be a sloughed biofilm which has become detached from the pre-treatment equipment. Bacteria arriving at the membrane surface in this compromised condition may produce EPS as a defence mechanism which, in turn, will make the bacteria resistant to biocide and more difficult to eliminate. This oxidant resistant biofilm will result in significant energy losses.
- It is possible that non viable micro- organism in the water supply, following the chlorination process, can act as a nutrient source for other bacteria.
- Chlorine may break down humic acid into smaller compounds which may then become available as a nutrient source.

REHARDENING

Water produced by the RO process is unstable and slightly corrosive. An LSI of –3 was measured in the Victoria permeate. A rehardening process is included in the overall process, to stabilise the water thus providing a potable water supply acceptable to consumers. Stabilisation of permeate reduces corrosion of the conveyance system.

Rehardening can be achieved by adding limestone, hydrated lime, soda ash or caustic soda to the permeate stream. In practise on the island where the sea water temperature was higher than expected, the rehardening process reached equilibrium with limestone quicker than we had calculated. The net result was a pH in excess of 9. An additional acid injection step is now being added, to reduce the pH to 8.5.

MEMBRANE CLEANING

Membranes are cleaned with two types of cleaning agents. The first is an alkaline cleaning agent effective against a wide range of organic foulants. The second cleaning agent is a blend of citric acid and biodispersants, suitable for removing inorganic scale and iron deposits.

During the dry period of the year, April to October, the plant is offline. During this time, membranes are to be preserved with in 1% sulphur dioxide solution. Sulphur dioxide is oxidised slowly with time, hence the preservation solution is replaced with fresh solution, once a month. One needs to allow for operating staff to fulfil this operation during this downtime period.

SEA WATER TEMPERATURE

Both seasonal and local variations in seawater temperature have a marked effect on the performance of the desalination facility. For a 2.5°C rise in seawater temperature, there is a corresponding 1 bar drop in operating pressure and a 25 mg/l increase in TDS.

Table 4. Seawater temperature versus operating pressure.

Plant	**Sea water temperature (°C)**	**Feed pressure (Bar)**	**Permeate TDS (mg/l)**
Providence	29 to 32	55 to 56	250 to 280
West Coast	26 to 28	59 to 60	230 to 250
La Digue	27 to 28	60 to 62	220 to 250
Praslin	28 to 31	62 to 64	190 to 200

Data in table 4 partially reflects this correlation. Note that other factors skew the direct correlation.

PILOT STUDIES

SWRO technology is a mature one, with an abundance of published data to define typical operating conditions. Most seawater applications can be designed without the aid of pilot studies.

However, if a Contractor is entering into a competitive bid where long term operating cost are part of the evaluation procedure, then pilot trials are a great benefit. The rate of membrane fouling is an important parameter in determining the operating costs. The rate of membrane fouling differs from one location to the next, as we have seen from our experience on the island.

The rate of fouling affects the frequency of cleaning and the hence the cost of cleaning chemicals. As the membranes foul up, the feed pressure has to be increased to achieve the same permeate flow. Hence the power consumption increases as the membranes become more fouled.

Many Municipal Tenders are issued without due time for pilot studies. Hence, suppliers offer process guarantees and operating cost estimates based on past experience. The associated risk is to both Client and Contractor is high. A wide feed pressure variation of 4 bar was recorded, between the four plants now operating in Seychelles. This variation can be attributed to a variation in seawater temperature and seawater quality.

CLIENT/CONSULTANT ISSUES

Two areas of the design are critical to obtain accurate project cost estimates. These factors are membrane fouling rates and intake designs. Pilot studies help to predict the long term rate of fouling and hence the related operating costs, while upfront testwork help to identify the most economical intake system.

To find the answers to the above usually requires considerable upfront cost, especially if the plant location is remote. Project risk could be minimised if the Consultant provides additional data in the Tender Document.

PIPING

Both stainless steel and HDPE were used on this installation. Each have their own advantage and disadvantages. Stainless steel is more robust and easier to install than HDPE, but more expensive. HDPE is less expensive, more corrosion resistant, but less robust and long lasting. Weld failures are possible at pressure of 10 bar.

SAFETY ISSUES

At the West Coast plant (refer to figure 5), the SWRO plant is situated very close to a school. Before the plant was started up, an evacuation procedure had to be drawn up for the school, in the event of a chlorine or SO_2 leak.

ENVIRONMENTAL IMPACTS

When installing an intake pipe along a coral shelf, damage to the reef is unavoidable. A Contractor may be forced by environmental pressure, to use a more expensive technique to secure the pipe than anticipated at Tender stage. The procedure can also be a time consuming one as we found at West Coast, where installation of the intake pipe took two months.

Other environmental impacts worth mentioning are death of sea life and detrimental effects on ground water aquifiers. Sea life can be sucked the intake screen, while beach wells may cause ingress of seawater into the ground water aquifiers.

Figure 5. West Coast site.

MEMBRANE STORAGE

The Victoria SWRO plant was commissioned six months before the other three facilities. The operating pressure on West Coast, Praslin and La Digue was 67 bar at start-up, around 7 bar higher than the Victoria plant at start-up. Following an acid cleaning procedure, the start-up pressure was reduced to 60 bar on each plant. This phenomenon was explained by the non-ideal storage conditions. Membranes were stored in a metal storeroom, without air-conditioning. New membrane elements are stored in preservative solution. Upon opening of new elements, we found them to be discoloured, an indication of oxidisation.

RUNNING COSTS

The operating cost to produce potable water by SWRO is in the range from US$ 0.7 to US$1.0 /m³ (2) while average delivered cost of water by conventional treatment falls in the range of US$ 0.38 to US$ 0.5/m³. In this case, operating cost to produce 1 m³ of water is R 8.5 per cubic metre of permeate, with power being 51% of the total operating cost.

The cost of power on the island is 3 to 4 times more expensive than SA as it is generated from diesel. Cost of power in Seychelles is R 0.9 per kWh

CONCLUSION

The design and operation of a SWRO plant is a mature technology. However a few areas of the design require special attention, in order to prevent delays and unexpected additional costs to a Contract. Factors to pay special attention are the design of intake and the rate of fouling. Although the rate of fouling has long been an important parameter to estimate, it is difficult to predict without pilot studies. Selection of an intake system can be determined at tender stage with the right level of investigation, rather than having to change the design and costing later in the Construction phase of the project.

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