Desalination and Energy Efficiency for a Uranium Mine in Namibia

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Abstract

Water is a key component in the mining process. With mines often located in remote, arid areas, having readily accessible water for both process requirements and regional drinking consumption is important for successful operations. The availability and advances in desalination technology, such as high efficiency membranes and isobaric energy recovery devices, have made seawater desalination a viable solution for water supply in mining applications.

Southern Africa's Namibia has abundant natural resources of diamonds, copper, uranium, silver, tungsten and lead, and is the world's fifth-largest producer of uranium. It also has, what is considered to be, one of the driest climates in the world with erratic and sparse rainfalls. Since water is a critical factor in extraction mining processes, it makes sense that seawater reverse osmosis (SWRO) desalination plants are being built to address this economic need. The 55,000 m^3/day Trekkopje seawater desalination process for Areva Resources Namibia (Pty) Ltd (built by South African desalination specialist company Keyplan), and other plants around the world are being developed to supply water for mining applications.

The Trekkopje Desalination Project in the Erongo Region, Namibia utilizes high-efficiency TM820F-400 and TM820E-400 membrane elements produced by Toray Membrane USA, Inc. a wholly owned subsidiary of Toray Industries, Japan. These membranes elements meet the product water requirements of less than 750 milligrams per liter (mg/L) salinity and less than 1.75 mg/L boron while operating at relatively low membrane feed pressures. The process also uses PX Pressure Exchanger energy recovery devices (ERDs) by Energy Recovery, Inc (ERI) to reduce the duty of the high-pressure pumps. These devices seal the high-pressure portion of the process, making the high-pressure pump flow rate and the membrane recovery rate independent and adjustable when feedwater and process conditions change. Advanced ERDs in combination with high-efficiency membranes reduce process energy consumption and cut operating costs compared to legacy SWRO processes.

The authors present energy saving solutions for desalination water supply for mining applications. Detailed design data for the Uranium mining desalination plant are given. Environment and economic-conscious owners and operators will learn methods of design and operation of desalination systems in mining, which can be easily extrapolated to many other industrial needs, and how to minimize the total cost of ownership of a desalination process.

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I. INTRODUCTION

The Seawater Desalination plant, announced mid-2007, will provide water for a uranium mine in Namibia. It has been designed and is currently under construction by desalination specialists Keyplan Water Treatment (Pty) Ltd. Once complete, the plant will be capable of delivering 20 million cubic metres per year (m^3 per year) of treated water that will be pumped approximately 50 kilometers (km) by overland pipeline to the Trekkopje mine. The mine is owned by Areva Resources Namibia (Pty) Ltd., previously named UraMin Namibia (Pty) Ltd.

The desalination plant, which is located near Wlotskasbaken, approximately 30km north of Swakopmund, received a positive Record of Decision in February 2008 after submission of the required Environmental Impact Assessment study. Since then, the desalination project has kicked into high gear with construction activities underway. The plant is expected to begin delivering water through the second half of 2009 in preparation for mine activities to begin, thereafter ramping up to full production.

1.1 Water Requirement for Mining

The Trekkopje Uranium Project is a low-grade, shallow uranium deposit that is to be mined by open cast methods. The project is being developed by Areva Resources Namibia, and is situated in the Namib Desert in the Erongo Region of Namibia. The Trekkopje mine is expected to require 20 million m^3 per year of fresh water. Various options were initially explored to provide water for the project, including groundwater and surface water resources.

1.1.1 Climate and Rainfall - The central Namib Desert consists of a flat, gently-sloping plain with few topographic features. Because of this, the steady gradients affect rainfall, fog, humidity, temperature, and wind patterns developing between the coast and the interior. The annual mean rainfall along the coast between Swakopmund and Henties Bay is less than 15 millimeters per annum. Fog, a more reliable and predictable occurrence in the western Namib than rainfall, occurs approximately 150 days of the year and extends over 100 km inland from the coast. Evaporation increases steadily from the coast inland where it exceeds precipitation by 10-60 times. At the coast, wind speeds average approximately 3 meters per second. Hot “land” wind conditions from the east can raise the temperature, which averages 15 ^{o}C, to over 30 ^{o}C. The average wind direction is from the south west (from the coast inland).

1.1.2 Surface water supply - Namibia is a hyper-arid country. Regionally, growing demand for water, resulting from population growth, economic development and urbanization, is placing increasing pressure on existing water sources. In the Erongo Region, Swakopmund, Uis, Arandis, Rössing Mine, Langer Heinrich Uranium and the Trekkopje site lie outside the Omaruru River Catchment but are nonetheless considered to be part of the basin. The national water supply corporation (Namwater) currently augments the water supply to these towns and mines via the Omdel water transfer scheme and dam in the lower portion of the Omaruru catchment area.

1.1.3 Ground water supply - Existing water resources, primarily from aquifers in the region, along with the aging infrastructure are insufficient to supply the growing water demand much beyond 2010 to 2012. Namwater is in the process of a major infrastructure upgrade to meet this demand. Current abstraction from fresh water aquifers exceeds the yield and the groundwater is at risk of being contaminated by incursion of coastal brackish water.

1.2 Water production by Desalination

There being insufficient surface water or groundwater resources in the Erongo Region to provide the required volume for additional mining in the region, desalination was considered to be the optimal solution for water provision to the project.

1.2.1 Marine Environment - The water quality and temperature is largely affected by the currents along the west coast of Africa and the prevailing wind and weather conditions. The cold Benguela current originates in Antarctica and flows like a river up the west coast as far as Angola. It is very rich in plankton due to the cold-water upwelling system, caused by the prevailing south to southwest winds. The coastal, wind-induced upwelling characterising the Namibian coastline is the principle physical process which shapes the marine ecology of the central Benguela region.

Northerly winds often intrude during the warm summer months, driving before them currents of warm tropical water that cancel out the cold Benguela current for a few days or weeks at a time. The phytoplankton can no longer prosper in the warm nutrient-depleted waters and they sink to the ocean floor and rot away. During the calm conditions following the northerly winds, the layer of anaerobic water normally confined to a thin layer at the bottom of the ocean floor rises. Sometimes the layer reaches the surface and a band of oxygen-depleted water moves towards the shore.

1.2.2 Seawater Temperatures - The seawater temperature varies between 10°C and 22°C, averaging 14.9°C. During the non-upwelling season in summer, daily seawater temperature fluctuations of several degrees are common along the near-shore coast.

1.2.3 Seawater Salinity – The salinity in the South Atlantic Central Water (SACW) ranges between 34.5 to 35.5 g/L. It is expected that higher salinities occur when warmer water is introduced along the Namibian coast. Warmer water can come from Angolan tropical currents during periods when northerly winds counter the effects of the strong Benguela currents.

1.3 Justification for Development of Desalination

Water and power are two of the main limiting factors affecting development in Namibia. The UN Comprehensive Freshwater Assessment (UNCSD, 1997) showed that Southern Africa is one of the most vulnerable regions for water-related problems. The water resources problem is seen as a potential limit to development and a stress on population and economic growth. The assessment classified Botswana and Namibia’s water resources as stressed and moving toward very vulnerable by 2025. Namibia faces an extremely difficult situation in securing enough water to allow further development of the country. Namibia is the driest country where 98 percent of the country is classified as arid or semi arid.

Namibia ranks low on the human development index, and increased commercial activity and investment is encouraged by the government to help to address this low development status. This increased commercial activity cannot be achieved without access to reliable and adequate water and power resources.

1.4 The Challenges for Desalination

The main goals of the desalination plant and associated infrastructure are to overcome the following challenges:

- A relatively unprotected coastline, where the water temperature and salinity levels vary.
- Changes in water quality as a result of climate-induced upwelling and the possibility of sulphides and red tides
- Deliver the required quantity of 20 million m^3 per year of fresh water from the selected desalination site to the Trekkopje mine over a distance of approximately 50 km to an altitude in excess of 500m above mean sea level.
- Provide the power required for desalination and transfer of water to the Trekkopje mine.

The desalination plant construction and operation has great strategic implications for the Erongo region and for Namibia. The studies undertaken for the provision of water revealed that there are insufficient water resources to provide for existing development levels in the Erongo region much beyond 2010. At inception of the project, the desalination plant was to be designed not only to accommodate the mine's requirements but for possible future water supply to other users in the Erongo Region. However the current design is sufficient for the expected requirement of the Trekkopje Mine only.

This paper presents certain key aspects of the desalination process and describes how the desalination plant will be able to operate over the range of expected water temperatures and salinities. The paper also describes the incorporation of Energy Recovery, Inc. (ERI) PX Pressure Exchanger devices to minimize the power consumption for desalination.

II. PROJECT DESCRIPTION

An annual net production of treated water of 20,000,000 m^3 per year equates to 55,000 m^3/day with an associated seawater abstraction rate of 139,300 m^3/day. An overall water recovery of 38 to 40% will be achieved, meaning that 40% of the seawater will be converted into treated water, while the remaining 60% will be returned to the sea. The intake system, however, has been designed to abstract 361,800 m^3/day of seawater to cater for a possible future water demand of 45,000,000 m^3 per year. The plant is to be built in a modular fashion to allow for future expansion to meet future commercial and industrial needs.

The overall project infrastructure consists of:

- two 1200 meter seawater intake pipelines and a 600 meter brine disposal pipeline,
- a seawater transfer pump station,
- a desalination process plant,
- three treated water transfer pump stations and pipeline to the mine,
- a 54,000 m^3 terminal water storage reservoir at the Trekkopje mine, and
- a 132 kilovolt power line from the Kahn Sub-Station to the desalination plant.

2.1 Water Quality

The quality of the seawater along the Namibian coast is nutrient rich, has high plankton levels and contains kelp forests. The high levels of biological growth along the Namibian coast will likely result in significant biofouling of the seawater intake pipelines and structures.

Swakopmund is subject to an infrequent "red tide" phenomenon, upwelling of water containing low levels of oxygen, and periods of stagnation. Stagnation allows biological debris to become anaerobic, releasing hydrogen sulfide into the water column, thereby raising seabed sediments.

2.1.1 Seawater Temperatures - Seawater temperature records indicate an average water temperature of 15 ºC (Figure 1). The desalination plant has been designed to produce the required amount of water over a temperature range of between 11 and 23 ºC.

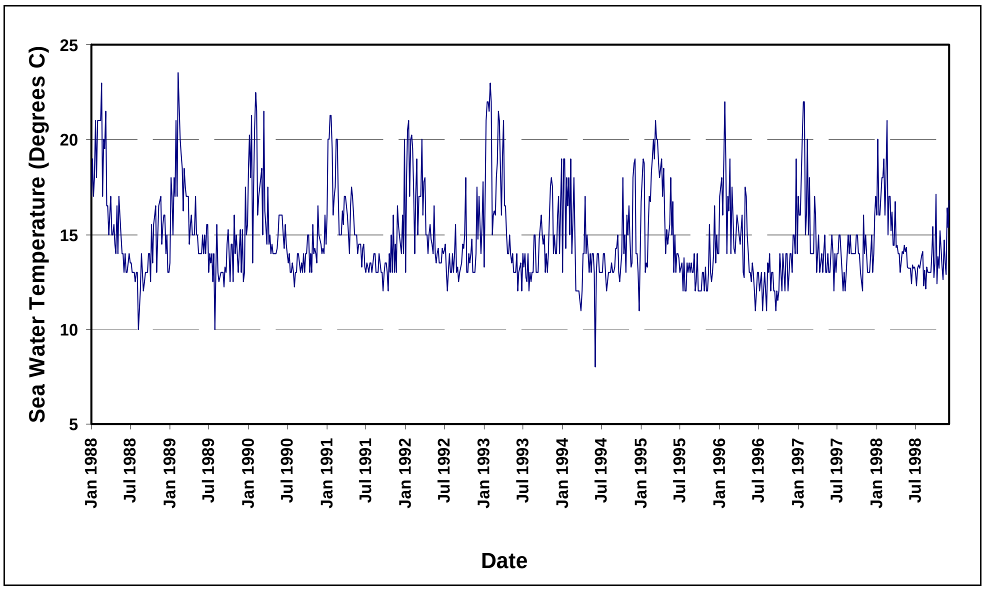

Figure 1 – Seawater temperature at Swakopmund
(95% min 12.5 ºC ; Average 14.9 ºC ; 95% max 19.0 ºC)

2.1.2 Seawater Suspended Solids – Turbidity measurements and sediment traps were used to gather data regarding the levels of sediment in the water column over a matrix of positions through the surf-zone and at varying depths near the selected intake position. The data was used to verify predictions made using the Van Rijn (2004) model, employing hindcast wave conditions, converted to nearshore by means of existing wave transformation results. Considering the accuracy limitations of the wave input data, the predicted versus measured concentrations were consistent. The total sediment that can be expected to enter the intake includes "Fines," or particles typically less than 60micron, and "Sediment" which has a tendency to settle but can be re-suspended in the water. Based on expected wave conditions, excluding storm events where excessive wave action is likely to stir up sediments, it is predicted that the material entering at the intake pipe would have an average concentration of 21.2 mg/L of suspended solids.

2.1.3 Seawater Salinity - The salinity in the South Atlantic Central Water (SACW) ranges between 34.5 to 35.5 g/L. During the period 1964 to 1966 the feedwater salinity varied from 34.9 to 35.3 g/L (Pieterse et al, 1967) with minimum figures being recorded in the period October to December of each year.

Monteio et al (2006) reported increased temperatures and higher salinity in the central Benguela region between 2000 to 2003. Recently samples taken during March to April indicated higher salinity up to 35.7 g/L. This is typical of what may occur when warmer water is introduced by Angolan tropical currents. Samples of seawater taken were used to provide a design basis for the desalination plant (Table 1).

Table 1 – Design seawater and product water quality

Element	Design Seawater Quality	Design Product Water Quality	(Namwater) (Guideline)
pH	8.0	6.0 – 9.0	Group A
TDS mg/L	34 500 – 36 000	< 1000	Group A
Conductivity mS/m	4 750 – 4 920	< 150	Group A
Turbidity NTU	5.0	< 1.0	Group A
Suspended Solids mg/L	21.0		
Sodium, Na mg/L	11 077	< 400 *	Group B
Calcium, Ca mg/L	418	< 150	Group A
Magnesium, Mg mg/L	1 370	< 70	Group A
Potassium, K mg/L	482	< 200	Group A
Chloride, Cl mg/L	20 426	< 600 *	Group B
Nitrate, NO3 mg/L N	0.4	< 10	Group A
Sulfate, SO4 mg/L	2 663	< 200	Group A
Boron, B mg/L	3.9	< 2.0 *	Group B
Fluoride, F mg/L	1.0	< 1.5	Group A

2.1.4 Product Water Quality - The desalination plant is to produce water for heap leaching of uranium at the Trekkopje mine. Some of the water will be for potable uses at the mine. The product water will, under most circumstances, meet the Namibian Water Quality Guidelines Group A, used to define water of exceptional quality (see Table 1). However, during periods where the temperature of the seawater increases, the determinands of sodium, chloride and boron will always meet the Namibian Water Quality Guidelines Group B (remaining acceptable as potable water).

2.2 Environmental Impact Assessment and Site Selection

Once desalination was chosen, the EIA required that follow up investigations related to the optimal location of the desalination plant be conducted. The factors considered in the site selection process were:

- Technical issues such as plant design and pumping requirements
- Financial issues such as cost of pumps, pipelines, consumables affected by the location
- Environmental and social issues associated with the various sites
- Power supply feasibility and cost
- The carbon footprint of the operation

Based on an extensive risk assessment, the selected site for the desalination plant is an abandoned previously excavated and disturbed area 3.5 km north of Wlotzkasbaken on the eastern side of the main road between Swakopmund and Henties Bay. A permanent water pipeline and powerline will traverse inland along an existing quarry road to the Trekkopje mine. See Figures 2 and 3.

Figure 2 – Selected Location for the Desalination Plant

Figure 3 – View of existing Location and proposed Mitigation plan

Following an extensive consultative process and submission of the EIA report, a positive Record of Decision for the Project to commence was received in February 2008.

2.3 Seawater Intake and Brine Disposal System

The intake system is designed to draw in a seawater volume of 15,076 m^3/hr, which caters for a future potential water demand of 45,000,000 m^3/year. The seawater intake system consists of two (2) 1,200 meter, 1,200 NB diameter carbon steel intake pipes and one 600 meter, 1,200 NB diameter brine discharge pipe, each with a concrete weight coating on the outside and suitable corrosion protection on the inside.

A seawater intake structure is provided with 40 mm inlet screens which can be removed for cleaning or replaced. The intake and brine pipelines will be placed in a 1.5 meter deep trench in the sea bed rock, through the surf zone for which a 400m long temporary jetty will be erected.

The water will be pumped to the desalination plant from a pump station near the beach. The pump station is designed to allow pigging of the intake lines. A separate transformer and switchgear provide power for four (4) Sulzer low NPSH seawater intake pumps. One (1) 1200 NB diameter glass fiber reinforced (GRP) seawater transfer pipe will be installed, and one (1) 1000 NB diameter GRP pipe will be used for the brine return from the desalination plant to the sea outfall pipeline.

In order to minimize the potential marine ecology impact of the brine disposal, discharge via a marine pipeline into deep water is planned. The design of the diffusers, including the layout and diameter, is such that maximum mixing is targeted. Initial modeling has shown this design to be optimal for maximum dispersion of the brine within a maximum distance of 20 meters from the point of discharge.

2.4 Pretreatment

The water quality of seawater along the Namibian coast is nutrient rich, has high plankton levels, and contains kelp forests. Macro-fouling from mussels, clams, oysters, sea anemones and barnacles, combined with micro-fouling from bacteria, slime and algae, greatly restrict the flow of water along pipelines and in process equipment. This can be controlled using irregular shock dosing of chlorine into the inlet structure and into the seawater entering the intake pipelines.

Swakopmund is subject to an infrequent phenomenon “red tides” and upwelling of low oxygenated water, together with hydrogen sulfide from decaying organic material which raises seabed sediments. When these events occur, the desalination plant will have to be managed accordingly to ensure that effective water treatment can be achieved. The following pre-treatment technologies were selected.

2.4.1 Chlorination – Pulsing or irregular shock dosing of chlorine has been shown to be significantly better at controlling biofilm and macro-fouling in seawater cooling circuits than continuous dosing. Chlorine will be periodically dosed into the inlet structure and into the seawater entering the intake pipelines, thereby providing suitable contact time for oxidation. The level of chlorine will be adjusted to provide a target chlorine residual at the seawater transfer pump station.

The treatment of sulfides and upwellings will also be treated by chlorination. The process will monitor the oxidation reduction potential of the seawater to determine the required dose. Chlorine will be injected into the delivery pipeline, providing sufficient contact time in run down the pipeline to the desalination plant. The residual chlorine levels will be monitored at the desalination plant inlet to ensure that adequate oxidation is achieved.

2.4.2 Fine Screening - Seawater enters the desalination plant where it first passes through a set of 60 micron screens to capture the fine sediment and organic debris expected in the seawater. Due to the reported excessive biogrowth in the area, the 60 micron size was selected to ensure that mussel larvae do not enter the UF tanks and UF system where they could cause significant damage.

2.4.3 Ultrafiltration - Membrane filtration is becoming more common as pre-treatment for SWRO systems in general. Recent developments in ultrafiltration (UF) membrane technology have resulted in significant advances in reducing the cost of operation.

The variability of seawater quality along the west coast and the occurrence of higher levels of plankton would be a problem for multi-media filtration where coagulation is likely to be affected resulting in poor quality filtered water. The UF membrane, which remains a consistent barrier, will produce exceptional quality water during these periods of high suspended solids. The control system will detect these occurrences and automatically backwash the UF more frequently. Ultrafiltration, therefore, will consistently produce superior quality water to conventional pre-treatment for the desalination plant under the variable seawater conditions. Reverse osmosis membranes are thus protected more effectively against particle breakthrough which is common with sand filters; expensive and time consuming replacement of cartridge filters is averted.

Figure 4 – NORIT Seaguard Ultrafiltration Skid

The NORIT “Seaguard” ultrafiltration system was selected to remove turbidity, plankton, and bacteria in a system that is easy to control for plant operators, eliminates the need for coagulants and substantially reduces the plant footprint. Eleven parallel UF trains will be installed each capable of producing up to 700 m^3/hr of filtered seawater.

2.4.4 Scale and Fouling Control - Scaling and fouling will be controlled by antiscalant dosing. Although the alkalinity of the seawater is relatively high, due to the low recoveries, it is not necessary to lower the pH to control CaCO3 saturation. A specially developed antiscalant named Vitec SR from Avista Technologies, with good biodegradable properties, has been selected for this application.

2.5 Desalination

The seawater reverse osmosis (SWRO) process will use spiral-wound, thin-film composite polyamide membrane elements produced by Toray Membrane USA. Nine (9) independent, parallel SWRO trains are being installed. After the UF, a low pressure (LP) supply pump conveys water through a single pipe to the high pressure (HP) pump and energy recovery devices. The LP supply pumps convey 650 m^3/hr at 74 meters differential head and 86% efficiency with 200 kW motors. The motors are controlled by variable frequency drivers (VFDs) to save energy and assure constant feed pressure to the HP pumps and energy recovery devices.

Each SWRO train, with the design production capacity of 7008 m^3/d, uses 256 of both the Toray TM820E-400 and TM820L-400 membrane elements housed in Bel™ 1,200 psi 8M side-port pressure vessels. They are fed by a single Sulzer multistage centrifugal HP pump, capable of delivering 292 m^3/hr at 627 meters of differential head, driven by a 750 kW motor. The best efficiency point of these pumps is approximately 79%. Each train is also fed by a Sulzer centrifugal HP circulation/booster pump capable of delivering 343 m^3/hr at 50 meters head and 80.6% efficiency with 75 kW motors controlled by VFDs. Energy recovery is provided by an array of eight (8) ERI model PX-220 energy recovery devices with a capacity of 340 m^3/hr for each SWRO train.

Figure 5 shows a schematic diagram of the SWRO process for each train. The LP feed pump draws water from the RO feed tank and transfers it to the HP pump and ERI devices (Stream A). The flow from the HP pump (Stream C) joins the flow from the circulation pump and enters the SWRO membrane array (Stream E). Membrane reject (Stream G) enters the array of eight (8) PX-220 PX pressure exchanger devices which recover this pressure and transfer it to the incoming low pressure stream (Stream B). The resulting pressurized seawater stream (Stream D) is feed to the circulation pump. The flow rate of the LP brine stream (Stream H) is controlled within a set range which can be adjusted by the operations personnel on the control system to achieve a higher or lower overall recovery.

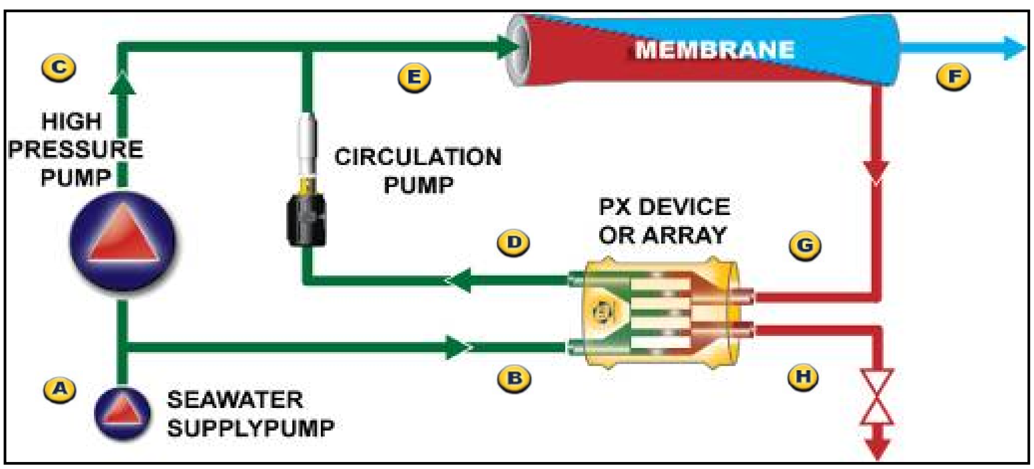

Figure 5 – Schematic Diagram of the SWRO Process

The SWRO process is started up with the following sequence, with reference to Figure 5:

1. Start the low pressure feed pump and establish a low pressure flow (Stream B – Stream H) through the pressure exchangers using a flow control valve at Stream H.

2. Start the circulation or booster pump to establish a high pressure flow (Stream G – Stream D) through the membrane train and pressure exchangers by controlling a VFD on the circulation pump.
3. Start the multistage high-pressure pump thereby pressurizing the membrane train. A permeate flow (Stream F) will be established based on the design and specification of the high pressure pump, the expected variation in seawater temperature and salinity, and the recovery that is achieved.

2.6 Post Treatment and Water Transfer System

The permeate from the SWRO is marginally corrosive due to low calcium and alkalinity. Limestone stabilization filters containing marble chips, followed by a small dose of soda-ash, will be used to ensure that a zero or slightly positive Langelier Saturation Index (LSI) is achieved. The water will then be less corrosive to concrete and steel piping. The stabilized water then flows into a 2000 m^3 small on-site reservoir that serves as a pump station surge tank before being pumped to the mine. The water will be transported via two (2) booster pump stations to a 54,000 m^3 terminal reservoir at the mine at an elevation of 520 m above mean sea level.

III. ENERGY RECOVERY

Power and energy recovery are an important factor when considering the implementation of new infrastructure. The power supply and carbon footprint offered by technology were included in the risk assessment process conducted under the EIA study.

3.1 Power Requirement for Desalination

The power required to drive the high pressure pump(s) is typically the largest component of the operating cost of SWRO systems. Most of the pressure energy in the feedwater flowing to the SWRO membranes leaves the membranes with the brine reject water (see Figure 5). A number of devices have been developed to recover pressure energy from brine reject streams. These energy recovery devices (ERD’s) may be catagorised as centrifugal and isobaric devices. Centrifugal ERD’s, including pelton wheels, turbochargers, and reverse running pumps, are often limited in capacity and have maximum net transfer efficiencies of 80%. Isobaric ERD’s, including piston-type work exchangers and the rotary PX Pressure Exchanger® device, provide unlimited capacity and a maximum operating efficiency of 98%.

3.2 The Operation of a Pressure Exchanger

The PX Pressure Exchanger energy recovery device facilitates pressure transfer from the high pressure brine reject stream to the low pressure seawater feed stream. It does this by putting the streams in direct momentary contact within the ducts of a rotor. The rotor is installed into a ceramic sleeve between two ceramic end covers with a precise narrow gap between them that, when filled with high pressure water, creates an almost frictionless hydrodynamic bearing.

At any given instant half the rotor is in contact with high pressure water and half the rotor is in contact with low pressure water. As the rotor turns, the ducts pass a sealing area that separates the high and low pressure. The reject is replaced with fresh seawater which is pressurized for the membranes while the spent brine is discarded from the system. This pressure exchange process is repeated in each duct with every rotation so that the ducts are continuously filling and discharging at a nominal rate of 240 cycles per second. The exchange process is illustrated in four steps in Figure 6.

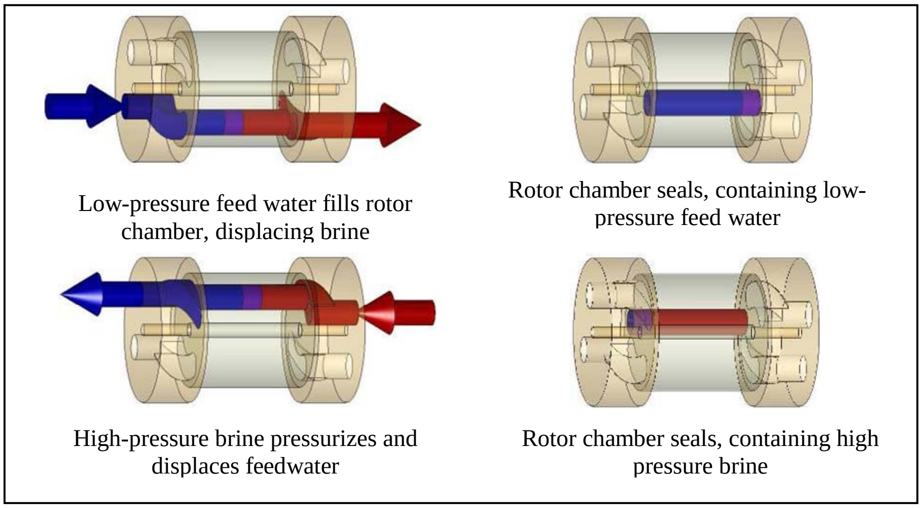

Figure 6 – Schematic Flow path through a PX unit

PX technology was selected because it provides maximum pressure-transfer efficiency despite changing water conditions. Isobaric ERDs such as the PX device are positive displacement devices, and, as such, they maintain nearly constant efficiency in recovering the brine pressure energy as the plant shifts from lower to higher salinity, lower to higher water temperature, adjustments in recovery rates and even changes in pressure due to membrane ageing or fouling. This is key for the optimal SWRO specific energy consumption.

3.3 Manifold Arrangement and Installation of Pressure Exchangers

As with membrane manifolds, even flow distribution in a PX array can be assured through proper manifold design and arrangement (Stover, et al 2007). This can be achieved with sufficiently large manifold diameters. The required diameter depends upon the orientation of the manifolds. Two manifold configurations are illustrated in Figure 7. In a “Z” flow scheme, the manifold inlet and outlet are at the opposite ends of the array. In a “U” flow scheme, the manifold inlet and outlet are at the same end of the array.

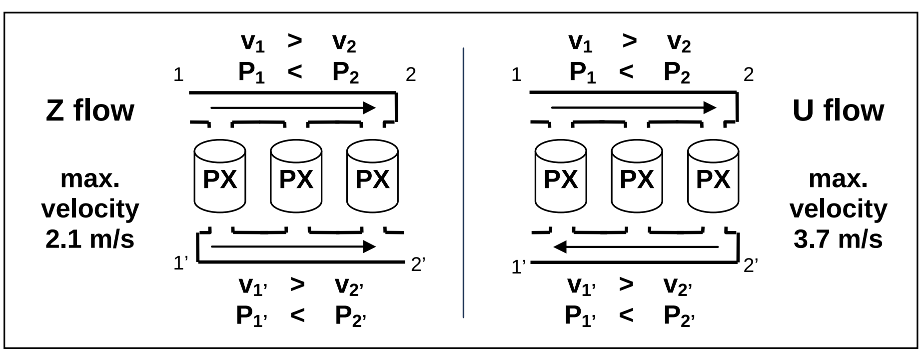

Figure 7 – Manifold flow Schemes

Considering the inlet (upper) manifolds in Figure 7, velocity decreases in the direction of flow as water diverts into the PX units, causing a pressure increase in the direction of flow. Friction losses in the header and fittings decreases pressure in the direction of flow, however, friction in PX device manifold headers minimal because the header is relatively short. Therefore, pressure tends to increase in the direction of flow in the inlet headers. Friction losses are greater in smaller-diameter headers, however, the velocity change and its impact on pressure is even greater in such systems. Similar considerations apply to the outlet (lower) manifolds in Figure 7.

Flow through the individual PX units depends upon the local pressure difference between the inlet and outlet manifolds according to Figure 8. For a given header diameter, the pressure differences between the inlet and outlet manifolds in a U flow configuration are more even than those in a Z flow configuration. Alternately, an even flow distribution along a PX device array can be achieved with a U flow configuration operating at a higher entrance velocity. This means smaller header diameters can be used if the manifolds are arranged for U flow.

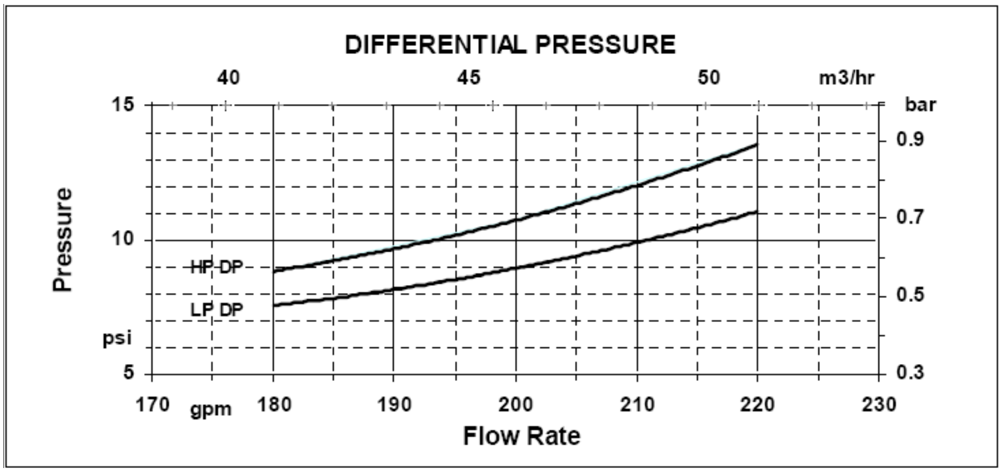

Figure 8 – Typical PX220 Device Characteristic curves

A photograph of one of the nine PX device arrays for the Trekkopje plant is given in Figure 9. The uppermost low-pressure manifold supplies seawater to this PX device array from the left. The bottom low-pressure manifold outlet is on the lower left (U configuration). The high-pressure manifolds behind the PX devices are also arranged in a U configuration with the inlet at the lower left and outlet at the upper left end.

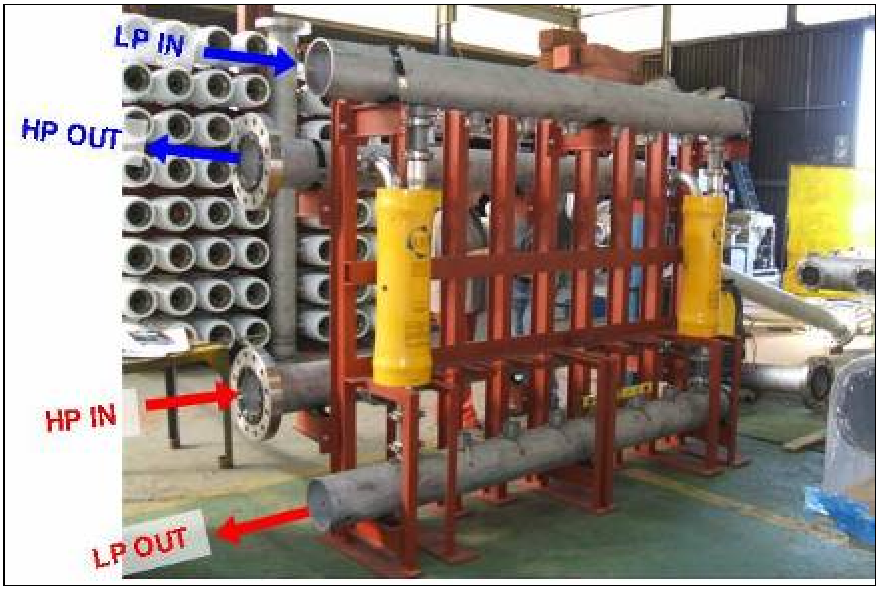

Figure 9 – ERD array with frame for 8 PX units in parallel (during construction)

IV. DESALINATION PROCESS PERFORMANCE PREDICTIONS

Figure 10 shows the predicted permeate flow as a function of membrane feedwater salinity with the seawater flow rate to the PX arrays held constant at 340 m^3/hr per train. A maximum permeate flow of 315 m^3/hr can be achieved at 34,500 milligrams per liter (mg/L) salinity and 22 deg C corresponding to the lowest salinity and highest temperature expected for the seawater. The minimum permeate flow is estimated to be 278 m^3/hr when the seawater salinity is as high as 36,500 mg/L at the lowest expected seawater temperature of 11 deg C.

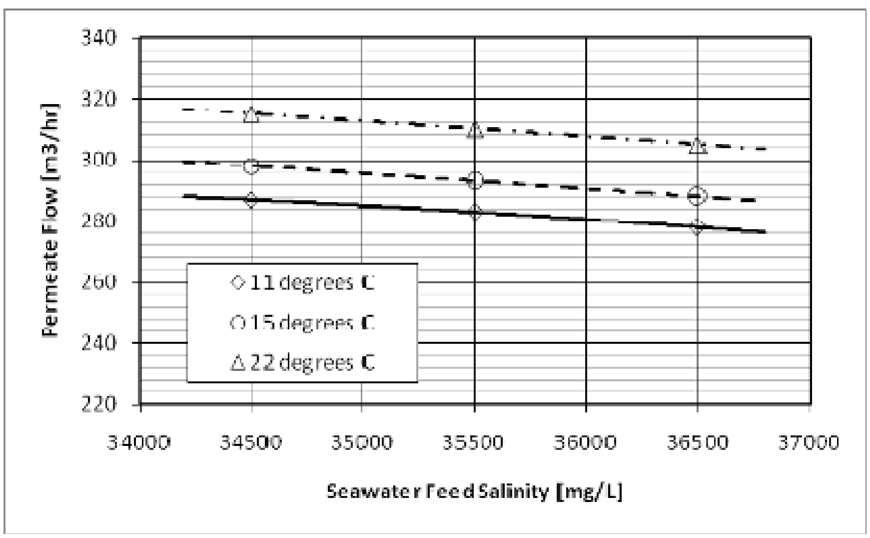

Figure 10 – Modeled Permeate Flow versus Salinity and Temperature

The philosophy of operation of the SWRO process is to maintain the flow and operation of the Energy Recovery system, and allow the recovery and permeate flow rate to vary along the pump curve of the high-pressure pump. The expected variation will be between 95% and 107% of the design duty point shown in Figure 11.

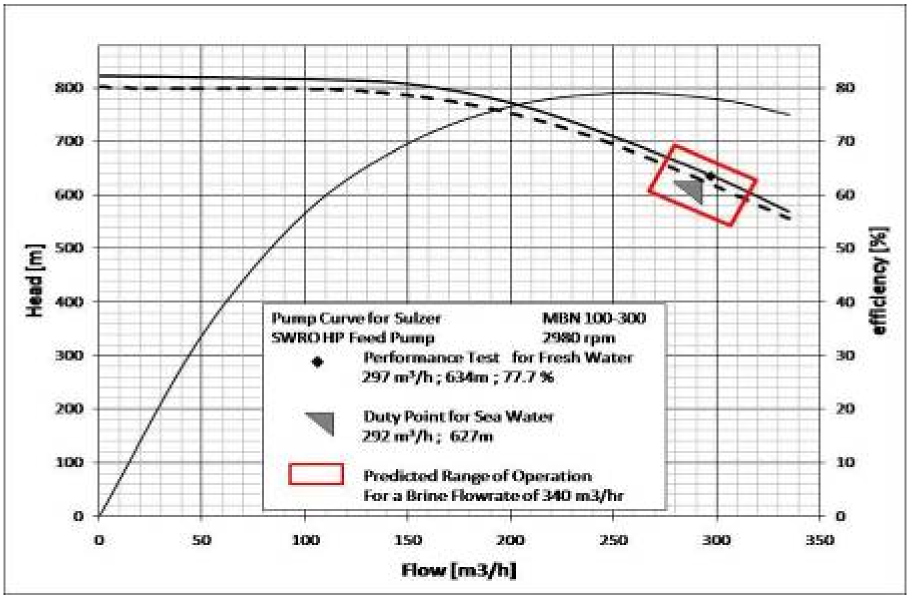

Figure 11 – Range of Operation of the High Pressure Feed Pump

The anticipated power consumption for the SWRO section of the desalination plant, including the supply pump, is estimated in Table 2. The total power consumption of 753 kW per train is approximately 57% of the power required by a SWRO system in which no energy recovery is included. The resulting specific energy consumption of the SWRO process is 2.58 kWh/m^3. The power consumption of the SWRO process excluding the supply pump is expected to be 2.36 kWh/m^3.

Table 2 – Power Model for the Trekkopje SWRO Train

		A	B	C	D	E	F	G	H
FLOW	m3/hr	635	338	297	338	635	292	343	343
PRESSURE	bar	3.0	3.0	63.0	61.0	63.0	0.0	62.0	2.2
SALINITY	mg/l	34,500	34,500	34,500	36,354	35,476	350	65,398	63,569

SYSTEM PARAMETERS

Membrane Differential	bar	1.0
Recovery	%	46%
Temperature	°C	15

PRESSURE EXCHANGERS

PX Units/Array	qty	8
Unit Flow	m3/hr	42.8
Lubrication Flow	%	1.3%
Differential HP side	bar	1.0
Differential LP side	bar	0.8
Salinity Increase @ membranes		2.8%
PX Overall Efficiency	%	96.0%
PX Power Savings	kW	580

HIGH PRESSURE PUMP

Pump efficiency	%	78%
Motor efficiency	%	96%
Power	kW	660

BOOSTER PUMP

Pump Efficiency	%	81%
Motor Efficiency	%	85%
Power	kW	28

SUPPLY PUMP

Pump efficiency	%	86%
Motor efficiency	%	95%
Power	kW	65

Total Power	**kW**	**753**
Specific Energy	**kWh/m3**	**2.58**

Additional energy improvements would have to come from an increase in the size of high-pressure pumps, resulting in added efficiency of these centrifugal devices. However, nine small trains will provide necessary flexibility that is considered more important than additional improvements in energy efficiency.

V. CONCLUSIONS

Water and power are two of the main limiting factors affecting development in Namibia. The water resources problem is seen as a potential limit to development and a stress on population and economic growth in the Erongo Region.

Due to the lack of surface and groundwater resources, seawater desalination was selected to provide the water required for the Trekkopje Uranium Mine Project. Highly-efficient energy recovery was identified by the EIA as an important aspect of the design of the desalination process that needed optimization. ERI PX Pressure Exchanger devices were selected and designed into the desalination plant to provide flexibility in operation to suit the seawater quality and temperature variations and the water demand expected from the mine.

Power consumption for the desalination section of the plant including supply pumping is expected to be 2.58 kWh/m^3. Additional energy improvements would have to come from an increase in the size of high-pressure pumps, resulting in added efficiency of these centrifugal devices. However, nine small trains provide necessary flexibility that is considered more important than additional improvements in energy efficiency.

VI. REFERENCES

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