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Seawater desalination off the Chilean coast for water supply to the mining industry

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ABSTRACT

Water is an important component in the mining industry. With mines often located in remote and dry areas, a sustainable supply of water is crucial. The development of seawater desalination, reduced membrane costs, and reduced energy consumption have made seawater a viable source of water supply for mining. Reliability of the desalination plant, quality of the water, and the availability of sufficient water supplies are the most important requirements to be fulfilled for the mining industry. Therefore the best available and proven technologies meeting the above-mentioned criteria should be used. The key for successfully operating a seawater desalination process based on reverse osmosis membranes (SWRO) is the pretreatment. Several tests conducted by researchers all over the world have proven that ultrafiltration (UF) provides an optimum pretreatment for the SWRO. The UF removes all the suspended solids and provides a substantial reduction in the microbiological activity. The plugging in of SWRO spacers is completely eliminated and the SWRO cleaning frequency can be drastically reduced. This paper presents the experience of using the UF as a pretreatment to the SWRO in Chile. Two desalination plants are described. Both the plants are of the desalination type dual membrane: ultrafiltration followed by reverse osmosis. One plant (GasAtacama) was commissioned in June 2011 and has since been successfully in operation. The second plant (Minera Candelaria) is currently under construction.

Keywords: Ultrafiltration; Seawater desalination; Reverse osmosis

1. Introduction

Water is an important component in the mining industry. With mines often located in remote and dry areas, a sustainable supply of water is crucial. The development of seawater desalination, reduced membrane costs, and reduced energy consumption have made seawater a viable source of water supply for mining.

Reliability of the desalination plant, quality of the water, and the availability of sufficient water supplies are the most important requirements to be fulfilled for the mining industry. Therefore, the best available and

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proven technologies meeting the above-mentioned criteria should be used.

The key for successfully operating a seawater desalination process based on reverse osmosis membranes (SWRO) is the pretreatment. Often dissolved air flotation (DAF) and/or dual media filters (DMF) are used, giving most of the time adequate protection to the SWRO. The waters at the Chilean coast are rich in nutrients, bacteria, algae, plankton, and macro-organisms and from time to time face "red tides": a rapid increase or accumulation of algae. To maintain the quality of the SWRO feed water within specifications at all times, experienced and skilled operators are needed. Despite awareness of the problems plaguing the operation of desalination plants, many such desalination plants with "conventional" pretreatment still face problems with regard to SWRO downtime or increased operational costs due to off-specification circumstances.

Several tests performed around the world have proven that ultrafiltration (UF) provides an optimum pretreatment for the SWRO. The UF will remove all the suspended solids and provides a substantial reduction in the microbiological activity. The plugging in of SWRO spacers is completely eliminated and the SWRO cleaning frequency can be drastically reduced.

2. Northern Chile

Northern Chile is home to the Atacama Desert and the Andes Mountains. The Atacama Desert is a strip of land on the Pacific coast, west of the Andes mountains covering 1,000 km in length and 105,000 km^2 in area. It is, according to several publications, the driest desert in the world. Along the coast, the aridity is, among other factors, the consequence of the Peru (Humboldt) Current, which is characterized by an upwelling of cold water from the ocean depths.

The Atacama Desert was one of the chief sources of Chile's wealth until World War I. The nitrate deposits in the central depression and in several basins of the coastal range were systematically mined after the mid-nineteenth century. Ports were built in various towns, such as e.g. Antofagasta, Mejillones and Caldera (Fig. 1). Prior to World War I, Chile had a world monopoly on nitrate; in quite a few years, 3,000,000 tons were extracted, and the taxes on its export amounted to half the government's revenues. The development of synthetic methods of fixing nitrogen has since led to a near total collapse of the market for mined nitrate.

The discovery of mineral reserves led to a new development of the mining industry in Northern Chile. The region's main source of revenue is copper

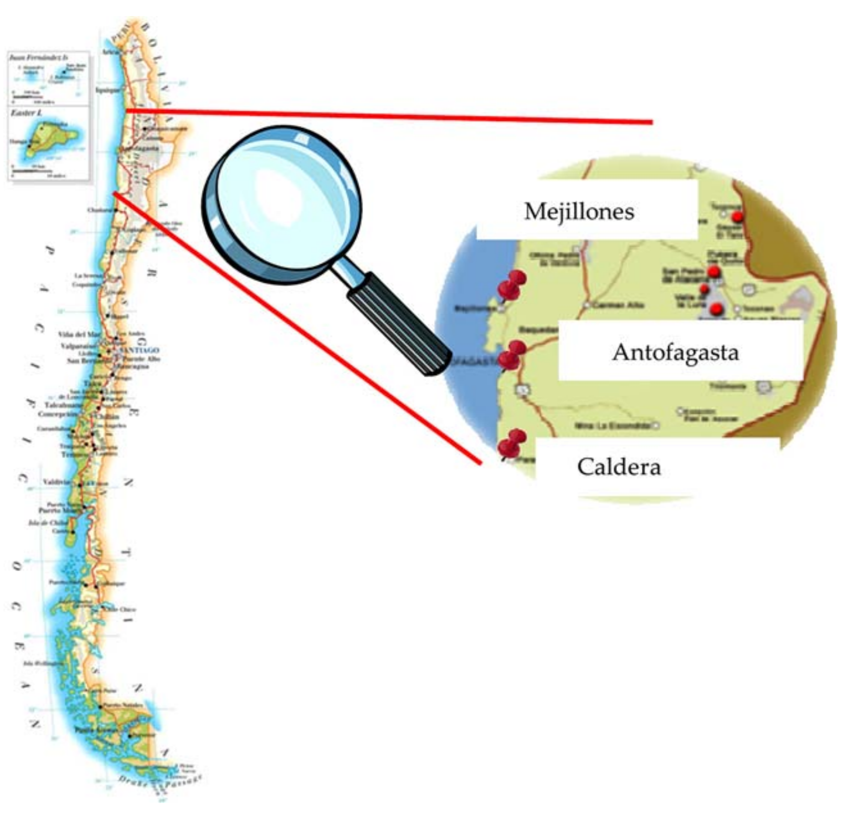

Fig. 1. Map of Chile.

mining. Several new mines are being set up and existing mines are increasing their capacity.

For any successful mining activity, the availability and proper management of water are key factors to its long-term sustainability. Desalination and specifically reverse osmosis have been identified as a potential source of freshwater. The challenge for running a desalination plant is huge, as one has to face such circumstances which are among the most difficult globally:

- Being the driest place on earth, absolute security of supply is of utmost importance. Due to the extreme and increasing scarcity, the political decision was reached to restrict the freshwater consumption for industrial purposes.
- The ocean water experiences upwelling of cold water, which has a higher viscosity than the warm water, with associated higher pumping cost.
- The water in the coastal area could suffer, all year round, from being infested with high algae and could be affected by the TOC concentrations, with e.g. red tide events.

3. Conventional pretreatment

The South-Pacific seawater is one of the most difficult seawater types to pretreat for reverse osmosis desalination. The conventional treatment consisting of dissolved air flotation followed by a singe-stage sand filtration was implemented, but this process also had its limits facing high peaks of the SDI. Especially during red tide events, this technology is unable to maintain the required SDI. A typical SDI level is 4–5, which is unacceptable for proper operation of spirally wound reverse osmosis elements.

In 2004, Degremont was awarded the construction contract of a 45 MLD SWRO plant. This plant is located at the Coloso Port, 15 km south of Antofagasta. The necessity for an even more complete pretreatment line was anticipated. Hence, Degremont proposed a high rate of dissolved air flotation, two stages of pressurized dual-media filtration and cartridge filters with 5 micron cut-off. A six-month pilot test was conducted, which confirmed the suitability of the selected treatment process: 90% of the SDI readings was below 3.

Although the conventional treatment with a two-stage dual-media filtration has proven to be suitable for, it is still a challenge to meet the water quality targets for feeding the reverse osmosis system. The location of water intake is critical and preference is given to a deep intake. Drawing water from 20 m below the surface will guarantee a more stable feed water quality. However, this process is fraught with a number of disadvantages, as mentioned below:

- The water temperature is typically 2–3 degrees lower than at the surface. This will increase the viscosity of the water and consequently the operating pressure, leading to a higher energy consumption.
- A higher installation cost for the intake structure that needs to be extended out further and deeper.

4. Ultrafiltration pretreatment Case I

GasAtacama operates a combined cycle thermal power plant with an installed capacity of 780 MW. The plant, located in Mejillones, supplies electricity to the residential market through the Northern Electricity Grid (SING) and to several of the largest mineyards in the northern region, Minera Escondida (BHP Billiton) and Minera Collahuasi (Anglo/Xstrata) among them.

The power plant uses the reverse osmosis seawater desalination as the single source of water. Based on an extensive tender evaluation, the customer selected a dual membrane desalination system: ultrafiltration pretreatment followed by reverse osmosis desalination.

The main contractor for this project was: Proyectos y Equipos (Chile). The UF and the SWRO system were supplied by Unitek (Argentina). The desalination plant was commissioned in June 2011 and has since been in operation. The desalinated water is fed to the final demineralization step.

The feed water is characterized by seasonal variations in turbidity: during autumn and winter the turbidity ranges from 1 to 5 NTU; during spring and summer the turbidity ranges from 3 to 35 NTU. Red tide events, with a typical frequency of 1–3 times a year with a duration of up to one week occur. The feed water SDI is 18 (SDI_5), or even immeasurable. The enclosed picture (Fig. 2) shows the fouling on the test membranes after 5 min of filtration.

The desalination plant has the following characteristics:

- An open intake with a suction level located at 5 m below sea level (3 m above seabed).
- Automatic backwashable 200 μ filters.
- Chemical addition: hypochlorite (desinfection) + coagulant.
- X-Flow Seaguard Ultrafiltration.

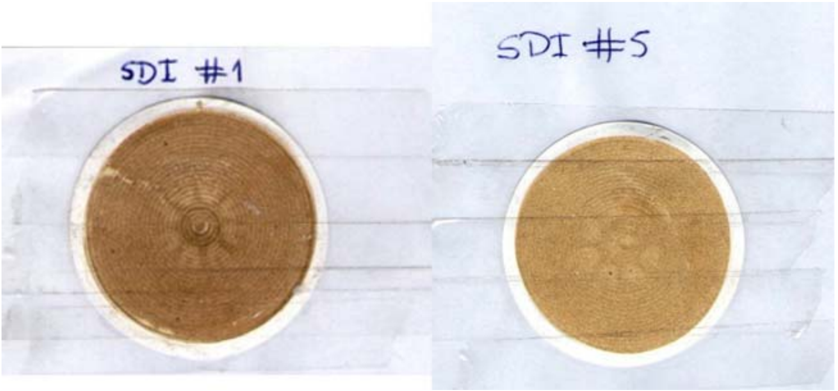

Fig. 2. SDI test membranes operated on feed water.

- An intermediate buffer tank that is being used for feeding the SWRO system and for feeding the UF backwash pumps.
- Micron cartridge filters.
- SWRO system with a capacity of 140 m^3/h.

The ultrafiltration system (Fig. 3) supplies a capacity of 285–350 m^3/h. The level in the intermediate buffer tank controls the flow set point of the UF system. This level will change, depending on the demand of the SWRO system and of the UF backwash pumps. The pretreatment prior to UF consists of only straining, therefore the UF design parameters have to be chosen conservatively. For a plant of this size, the cost implications of a conservative UF design are relatively small. The cost savings on pretreatment prior to UF outweigh the additional cost of UF membranes.

UF design parameters:

Flux rate:	75 $l/m^2 h$
Backwash interval:	25 min
CEB interval:	12 h
UF recovery:	±90%

Fig. 3. Ultrafiltration skids at GasAtacama.

Fig. 4. SDI test membrane operated on UF permeate.

The UF has performed in a very stable manner at these settings. All the UF permeate SDI tests show $SDI_{15} < 2$. The enclosed picture (Fig. 4) shows the fouling on the SDI test membranes after 15 min of filtration. The difference with the raw water SDI is striking.

The reverse osmosis has not required a CIP since the startup. The RO pressure drop and the permeate flow capacity remain stable since the startup. The enclosed picture (Fig. 5) shows the UF units (in the front) and the RO units (in the back) in operation.

Since 2000, a second desalination system has been in operation, in close proximity to the dual membrane plant. This system uses a conventional pretreatment: dissolved air flotation and single-stage media filters. According to the information given by the end user, the added value of a UF pretreatment is as follows:

- A strong reduction in chemicals' consumption
  Conventional plant: 25 ppm coagulant + flocculant addition
  Dual membrane plant: 1 ppm coagulant, no flocculant.

- No sludge treatment/disposal necessary for the dual membrane plant. The UF backwash water blended with RO brine meets all discharge limits.
- Low CIP frequency.
  Conventional plant: Autumn–winter, 1 CIP per month; Spring–summer, 2 CIPs per month
  Dual membrane plant: none.
- Low cartridge filter replacement.
  Conventional plant: every CIP.
  Dual membrane plant: negligible.

Fig. 5. Desalination plant at GasAtacama.

5. Ultrafiltration pretreatment Case II

Freeport McMoRan operates the Candelaria Mine, a mine that engages in the exploration and production of copper. The firm's facilities include a crushing plant, a 75,000t/d concentrator, and six mills. It has a port facility, Punta Padrones, located in Caldera, about 50 miles northwest of the mine. Discovered as a copper–gold–iron ore deposit in 1987, the mine has been in operation since 1993. The current supply of freshwater is carried out by aquifer abstraction. This is a non-sustainable solution: the aquifer is going to be depleted over time. In order to safeguard the supply of water a new desalination plant is under construction. The location is at Caldera Port and the desalination plant is scheduled to enter into operation in 2012.

The project will be executed in two phases: phase I will have a capacity of 30 MLD and will be expanded to 50.4 MLD in phase II. The original specification of the desalination plant was based on conventional pretreatment: dissolved air flotation, two-stage dual-media filtration followed by cartridge filtration. Alternative designs based on membrane pretreatment were allowed during the bidding phase.

Originally six parties prequalified for the bid. Only four parties chose to submit a bid as given below:

- Two parties bid according to the base tender requirements (conventional pretreatment).
- One party bid ultrafiltration as pretreatment.
- One party (Aqualia) bid Dissolved Air Flotation with either ultrafiltration or two-stage dual-media filtration plus cartridge filtration as the final polishing step. It should be noted that ultrafiltration was lower in investment and operational costs than the two-stage dual-media filtration followed by cartridge filtration.

Based on a thorough tender evaluation, taking into account the investment, operational costs, robustness of the process, and project capabilities, the project was awarded to Aqualia. Based on lower Capex and Opex, the decision was made to use ultrafiltration rather than media filtration. Phase one will start operation in 2012, phase two in 2013.

Compared to Case I (GasAtacama), the Candelaria project is characterized by the following changes made to the design:

- *Better pretreatment*: The Candelaria project uses dissolved air flotation as pretreatment prior to the ultrafiltration system. This allows for a higher membrane flux rate and a longer filtration interval.
- *Inline operation*: The UF is operated at elevated pressure. This process in turn creates a backpressure on the UF permeate side that allows for feeding directly into the SWRO high pressure pumps.
- *Brine backwash*: The UF system is backwashed with the SWRO concentrate (brine).
- All the units are backwashed in a sequence. This is a "train backwash": the backwash pump is started and all the units are backwashed one by one with the backwash pump continuously in operation. After backwash of the last unit, the pump is stopped and idles until the next backwash is called for.

The UF design parameters:

Flux rate:	82–85 l/m^2 h
Backwash interval:	40 min
CEB interval:	24 h
UF recovery:	97.5%

The cost implications of the design on this large-scale plant are quite considerable:

- A higher flux rate means a less membrane surface area. This translates to a reduction in the number of membrane elements and in the number of ultrafiltration units to be installed.
- A longer backwash interval decreases the downtime of the ultrafiltration system due to backwashing. This translates to a reduction in the number of membrane elements and in the number of membrane units as well.
- Inline operation eliminates the need for an intermediate storage tank, a transfer pump, and cartridge filters. This in turn reduces the cost and footprint.
- Brine backwash decreases the internal water consumption of the UF system. This translates to a reduction in the number of membrane elements and membrane units as well. It should be noted that this plant will be the first worldwide to employ brine backwash on a full-scale dual membrane desalination plant.
- The train backwash shows the following two effects:

(1) By minimizing the number of start/stop cycles on the backwash pump, the wear and tear is minimized.
(2) The overall running time of a backwash pump is reduced. This allows for a more efficient backwashing: less water loss and a reduced number of backwash pumps being required.

Fig. 6. Ultrafiltration skid.

The UF system has a net capacity of 2,778 m^3/h (phase I) and 4,158 m^3/h (phase II). During phase I, 11 membrane units will be installed. Fig. 6 shows a typical skid. This number will be increased to 16 units for phase II.

5.1. Comparison

The two ultrafiltration plants described above use the same Seaguard ultrafiltration membranes as pretreatment to a reverse osmosis system. The goal of the ultrafiltration system is identical in both case studies: proving the best possible pretreatment to a reverse osmosis step at the lowest cost.

The design approach in both case studies is however fundamentally different. The main driver for this difference in design is the size of the desalination system: one small and one large. Based on this different starting point, the outcome of the design process looks different. Table 1 below gives a comprehensive overview of the design differences and the selection criteria that drove these differences.

Historically large-scale dual membrane plants have been designed as the scaled-up versions of small-scale dual membrane plants: larger units based on the same design principles. The case study of the Candelaria Mine proves that this does not lead to the best design. Large-scale systems can take advantage of the economies of scale: e.g. a dissolved air flotation pretreatment system of 2,500 m^3/h is not ten times more expensive than a dissolved air flotation system of 250 m^3/h. When the above-mentioned factors are not taken into account, large-scale systems will become unnecessarily expensive and might outprice themselves against the alternative technologies, such as e.g. two-stage dual-media filters.

Table 1
Comparison of small and large scale pretreatment options

Systems size	Small		Large	
Item	Design	Selection criteria	Design	Selection criteria
Pretreatment	Strainer	Simple and low cost	Dissolved air flotation	Better pretreatment to provide savings in UF
Flexibility	Conservative design	Flow modifications by changing process parameters	Modular design	Flow modifications by adding membranes and units
Dual membrane system operation	Decoupled by means of intermediate tank	Easier to control both systems individually	Inline operation	Lower investment and operational costs
Backwash water	UF permeate	Easier to control both systems individually	RO concentrate	Higher systems recovery
Backwash strategy	Each unit individually backwashed	Better control of the intermediate tank level	Train backwash	Less water lossLower investment

The conclusion that can be arrive at is that a holistic approach needs to be adopted for designing large-scale desalination plants:

- Pretreatment selection should not be decided only based on feed water turbidity as this could lead to inadequate pretreatment and shortfalls in production of the desalination plant. It is therefore proposed to base SWRO pretreatment selection on multiple criteria.
- UF pretreatment has to be an integral part of the desalination plant.
- Investment in a UF pretreatment will be offset by the savings in investment and operational costs of the total desalination plant.
- Break tanks and intermediate pumping of seawater can be eliminated by installing UF in line with the SWRO low pressure feed line.
- Use of RO concentrate (brine) will increase the overall systems recovery and can provide investment savings due to smaller intake systems and operational savings due to lower pumping requirements.
- UF pretreatment is becoming the standard for SWRO pretreatment.